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# Development of a Real-Time Vibration Monitoring System for Drum Tester Machines Using ADXL345 Sensor and ESP32 Microcontroller

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**ABSTRACT**

This study focuses on developing a vibration level monitoring system for a drum tester machine, utilizing the ADXL345 sensor in conjunction with the ESP32 microcontroller and a web-based monitoring platform. The system was implemented at PT Astra Daihatsu Motor's Sunter Assembly Plant (SAP) located in Jakarta, Indonesia, for large-scale industrial use. The design aimed to boost precision in vibration monitoring and elevate workforce productivity. The sensor collects data, which is then sent to a MySQL database and shown in real-time on an LCD and through a Grafana-based web interface. Functional tests verified that all components performed as specified. The ESP32 microcontroller provided reliable Wi-Fi connectivity, and the ADXL345 sensor showed impressive accuracy in detecting vibration changes in both static and dynamic situations. Performance tests conducted over eight hours, with data collected at one-minute intervals, demonstrated consistent readings across all axes (X, Y, Z), highlighting the system's reliability. The implementation of this system resulted in enhanced efficiency in machine monitoring. The inspection interval has been extended from two weeks to one month, which has reduced the workforce requirements from two workers to one. Moreover, the time required for inspection was reduced from 20 minutes to only one minute. To summarize, this vibration monitoring system enhances the accuracy of real-time data, improves workforce efficiency, and ensures reliable monitoring of machine conditions. This offers a creative approach for industrial uses, enhancing operational efficiency and ensuring workplace safety.

## 1. Introduction

PT Astra Daihatsu Motor (ADM) is the sole brand holder agent (ATPM) for Daihatsu vehicles in Indonesia, authorized for the importation, assembly, and production of Daihatsu and Toyota-branded vehicles and related components [1]. Since its establishment in 1978, ADM has operated through several manufacturing facilities, one of which is the Sunter Assembly Plant (SAP) located in Jakarta. SAP has an annual production capacity of 330,000 units, with an average production time of 81 seconds per unit. In 2023, there was a significant increase in vehicle sales, particularly for the Gran Max model, which reached 32,000 units, accounting for 21.8% of total distribution between January and June.

As production volume continues to rise, efficiency and quality have become crucial factors in maintaining the company's competitiveness. Defect-free production is crucial for ensuring customer satisfaction and fostering long-term sales growth [2]. Therefore, the Quality Control (QC) division plays a vital role in ensuring that every unit produced meets the required quality standards before being distributed to customers [3]. One of the primary processes in Quality Control Inspection is the use of a drum tester [4], a testing device designed to verify the performance of vehicle indicators such as wipers, high beams, and dashboard indicators by running the vehicle at a speed of 60 km/h on a rotating drum. However, quality inspections using the drum tester face significant challenges, particularly in terms of maintenance [5, 6].

However, this process faces a major challenge, frequent maintenance issues with the pillow block bearings of the drum tester, particularly due to bearing wear and inadequate lubrication. These issues lead to excessive vibrations, causing operational inefficiencies, safety risks, and increased downtime [7, 8]. Currently, inspections are conducted manually every two weeks, taking about 20 minutes per session and requiring two personnel, which is both time-consuming and resource-intensive.

To overcome these limitations, this study proposes the development of a real-time IoT-based vibration monitoring system utilizing the ADXL345 accelerometer sensor and the ESP32 microcontroller [9, 10]. The system aims to automatically detect and report abnormal vibrations, enabling predictive maintenance and minimizing unscheduled downtimes. This is a direct response to the identified problems, including manual inspections, late fault detection, and inefficient workforce deployment.

Furthermore, the integration of the system with digital platforms such as MySQL databases and Grafana dashboards enables centralized and remote monitoring, significantly improving accessibility and decision-making. Looking forward, this system is also scalable and compatible with Artificial Intelligence (AI) and Big Data technologies, which can be used to analyze historical vibration patterns for predictive analytics and machine learning models. These enhancements will support the adoption of smart maintenance strategies and align with Industry 4.0 goals by transitioning from reactive to proactive maintenance approaches [11].

## 2. Methodology

A real-time vibration monitoring system is the main topic of this study. It is designed and implemented utilizing the ADXL345 accelerometer, ESP32 microcontroller, MySQL database, and Grafana visualization platform. The research consisted of four main phases: analysis of demands, system implementation, manufacturing (including PCB and enclosure design), and testing. There is also a detailed outline of the testing processes and system architecture.

### 2.1 Need Analysis

At this stage, an identification process was carried out to determine the necessary system for monitoring machine vibrations, particularly on the pillow block bearing of the drum tester at PT Astra Daihatsu Motor. The primary requirements include vibration measurement accuracy, data storage in MySQL [12], and data visualization through Grafana [13]. The ADXL345 sensor was selected due to its capability to measure vibrations along three axes [14, 15]. At the same time, the ESP32 microcontroller was used to connect the system to a Wi-Fi network. The hardware and its specifications are presented in Table 1, while the software and its specifications are shown in Table 2.

**Table 1.** Hardware used in the system

| No | Component | Specification |
|---|---|---|
| 1 | Battery 16850 | 3.7 V, 2.5 – 3.5 A |
| 2 | On/Off Switch | 2A |
| 3 | ESP32 microcontroller | Dual-core, Wi-Fi, Bluetooth, 2.4 GHz, 240 MHz, 520 KB SRAM, 4 MB Flash, 3.3 V. |
| 4 | Adxl345 accelerometer sensor | 3-Axis (X, Y, Z), ±2g/±4g/±8g/±16g range, I2C/SPI interface, 2 – 3.6 V |
| 5 | Stepdown | Input 4.5-28 V, Output 0.8-20 V, 3A max |
| 6 | LCD I2C | 16x2 character, I2C interface, 5V |
| 7 | AWG24 cable | 300V Max |

| No | Component | Specification |
|---|---|---|
| 8 | Box | 150mmx100mmx65mm |
| 9 | Plate | 20mmx15mmx10mm |

**Table 2.** Software used in the system

| Software | Usability |
|---|---|
| Arduino IDE | Used to program the ESP32 microcontroller |
| Notepad++ PhP | Used to program data from the microcontroller into the database |
| MySQL | Used as a storage database |
| Grafana | Used to visualize data. |

The first step in resolving the ongoing maintenance problems with the drum tester was to survey PT Astra Daihatsu Motor for signs of wear and vibration-related bearing failures in the pillow block. In order to resolve these concerns, essential system needs were determined, which comprise: Reliable detection of vibrations along the X, Y, and Z axes. The transmission and display of data in real-time. The ability to connect to Grafana and other web-based monitoring tools. Recording vibration data for future reference.

Due to its compact size, I²C/SPI interface, and sensitivity across a wide range of accelerations (±2g to ±16g), the ADXL345 sensor was selected. The ESP32 microcontroller was chosen due to its interoperability with Internet of Things applications, built-in Wi-Fi, and dual-core computing capabilities.

## 2.2 Implementation

The complete system architecture consists of the following subsystems. The mechanical design was developed to position the ADXL345 sensor on the drum tester machine. The electronic circuit design involved connecting the sensor to the ESP32 microcontroller using the I2C communication protocol. The software was developed using Arduino IDE to read sensor data, transmit it to a MySQL database, and display the results on Grafana. The Arduino code enables the ESP32 to connect the ADXL345 sensor to Wi-Fi and transmit data to the MySQL database. Grafana is utilized to visualize vibration data in a graphical form.

## 2.3 Manufacturing

The PCB was designed using Wokwi simulation software to ensure proper routing and minimal signal interference. After fabrication, continuity tests, voltage validation, and I2C communication checks were performed using a multimeter and oscilloscope to verify performance under operating conditions. The PCB was designed using Wokwi software, and the components were carefully soldered. All circuits were tested to ensure proper connections. The device enclosure was designed using AutoCAD and SolidWorks to house the electronic components and sensors. The enclosure was then cut and assembled according to the design specifications.

## 2.4 Testing

System testing involved three stages: electrical testing, functional testing, and performance testing under operational conditions. All vibration data was analyzed based on ISO 10816-3: Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts. This standard provides classification criteria for vibration severity in industrial machines. Data collected from the ADXL345 was converted to velocity (mm/s) and compared against the following standard zones: Zona A (Green), Zona B (Yellow), Zona C (Orange), and Zona D (Red).

The testing was conducted at PT. Astra Daihatsu Motor ensures that each component of the system functions properly. Hardware testing involved verifying the voltage levels on the ESP32 and ADXL345 sensor. In contrast, software testing ensured that sensor data was successfully transmitted to the MySQL database and displayed on Grafana. The testing was conducted by connecting the device to a power source and activating the MySQL database along with the Grafana web interface. The machine was subjected to vibrations, and the resulting vibration data was observed to ensure the accuracy of the sensor readings. The ISO 10816-3 [9] standard was used to measure machine vibration levels. The acquired data was categorized into different vibration severity levels: green (normal), yellow (alert), orange (critical), and red (dangerous), as illustrated in Fig. 1.

| Velocity Severety | | Velocity Range Limits and Machine Classes ISO Standard 10816 | | | |
|---|---|---|---|---|---|
| | | Small Machines Class I | Medium Machines Class II | Large Machines | |
| Mm/s RMS | In/s Peak | | | Rigid Supports Class III | Less Rigid Supports Class IV |
| 0.25 | 0.02 | Good | Good | Good | Good |
| 0.45 | 0.03 | Good | Good | Good | Good |
| 0.71 | 0.04 | Good | Good | Good | Good |
| 1.12 | 0.06 | Statisfactory | Good | Good | Good |
| 1.83 | 0.10 | Statisfactory | Statisfactory | Good | Good |
| 2.80 | 0.16 | Unstatisfactory (Alert) | Statisfactory | Statisfactory | Good |
| 4.50 | 0.25 | Unstatisfactory (Alert) | Unstatisfactory (Alert) | Statisfactory | Statisfactory |
| 7.10 | 0.40 | Unacceptable (Danger) | Unstatisfactory (Alert) | Unstatisfactory (Alert) | Statisfactory |
| 11.2 | 0.62 | Unacceptable (Danger) | Unacceptable (Danger) | Unstatisfactory (Alert) | Unstatisfactory (Alert) |
| 18.0 | 1.00 | Unacceptable (Danger) | Unacceptable (Danger) | Unacceptable (Danger) | Unstatisfactory (Alert) |
| 28.0 | 1.56 | Unacceptable (Danger) | Unacceptable (Danger) | Unacceptable (Danger) | Unacceptable (Danger) |
| 40.0 | 2.51 | Unacceptable (Danger) | Unacceptable (Danger) | Unacceptable (Danger) | Unacceptable (Danger) |

**Figure 1.** Level of vibration (ISO 10816-3)

## 3. Result and Discussion

### 3.1 Design and manufacture

In this study, a vibration monitoring system for the drum tester machine's pillow block bearing has been successfully developed. The system utilizes an ADXL345 sensor connected to a NodeMCU ESP32 microcontroller to monitor vibration levels in real time. The acquired data is transmitted and stored in a MySQL database and can be accessed through a monitoring interface using Grafana [16]. The development process began with a needs assessment and problem analysis. Field observations revealed that workers had to physically inspect the machine in the lower area, posing a risk of workplace accidents. To address this issue, a monitoring system capable of storing historical data online was implemented. The system design consists of both hardware and software components. The hardware includes a mechanical design created using AutoCAD and an electrical design developed using Fritzing. The software involves programming the microcontroller with Arduino IDE, as well as data processing and monitoring visualization through Grafana.

### 3.2 Product testing

The functional testing phase was conducted to ensure that each system component operates according to the predefined specifications. Key components, including the NodeMCU ESP32, LCD I2C 16x2, ADXL345 sensor, and ON/OFF button, were individually tested to assess their performance and compliance with the designed technical characteristics. This testing process involved verifying electrical performance, data communication, and the primary functionality of each module. Additionally, the integration of all components was examined to ensure the system operates synergistically without errors or data processing issues.

During the ESP32 microcontroller testing, an evaluation was performed to assess the stability of the power supply and network connectivity, which are critical aspects of system reliability. The test results indicated that the ESP32 functioned effectively within its specifications, maintaining stable operating voltage and uninterrupted Wi-Fi connectivity. The success of this testing confirms that the microcontroller module is a reliable central control unit for the system. The electrical verification results for the ESP32 are presented in Table 3.

**Table 3.** ESP32 verification result

| Testing | Input (Volt) | Output (Volt) |
|---|---|---|
| Pin GND | 5V | 5.02 |
| Pin3.3V | 5V | 3.28 |
| D212 (SCL) | - | 3.26 |
| D22 (SDA | - | 3.26 |

The ADXL345 sensor was tested to evaluate its accuracy in detecting changes in vibration acceleration. The tests were performed under both static and dynamic conditions to observe the sensor's response to applied vibrations. The results indicated that the sensor could accurately detect acceleration variations, both in a no-vibration state and when subjected to external shocks. The generated data consistently aligned with theoretical predictions, confirming that the ADXL345 sensor functions as expected. The electrical verification results for the ADXL345 sensor are presented in Table 4.

**Table 4.** ADLX345 verification result

| Testing | Input (mm/s) | Output (mm/s) | %Error |
|---|---|---|---|
| X Acceleration | 9.81 | 9.78 | 0.31 |
| Y Acceleration | -9.81 | -9.75 | 0.61 |
| Z Acceleration | 0 | 0.01 | 0.10 |

To ensure that the device is calibrated correctly and capable of displaying accurate values according to its function, functional testing was conducted by collecting data under two conditions. The first condition involved recording data for five minutes while the sensor remained stationary (Fig. 2). In the second test, data were collected for five minutes while the sensor was in motion [17]. Fig. 3 presents the results of the functional testing. Based on the data, it can be determined that the sensor operates as expected, as indicated by the variations in the recorded values when the sensor was in motion.

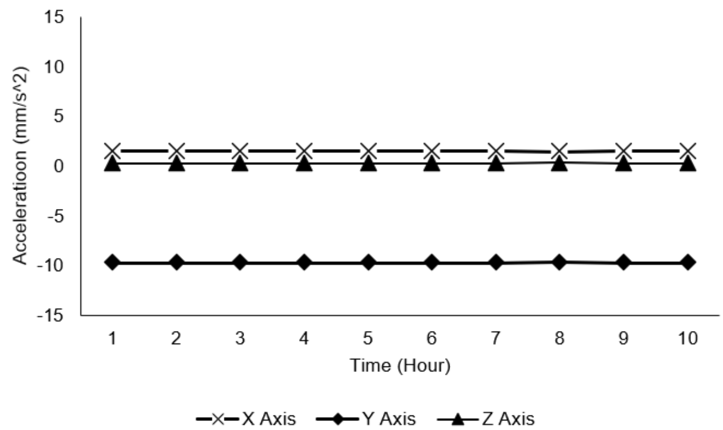


**Figure 2.** Sensor data in a stationary condition

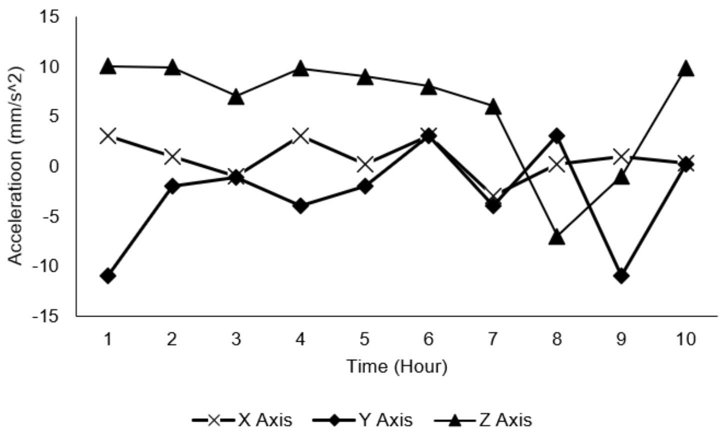


**Figure 3.** Sensor data in motion condition

In addition to individual component testing, an evaluation of the system's integration with the web-based monitoring platform was conducted. This test aimed to ensure that the data displayed on the LCD screen matched the information shown on the web-based monitoring interface. The results confirmed that there were no discrepancies between the data read by the hardware and the data transmitted to the monitoring system. This indicates that the data communication process between the device and the server functions reliably for long-term operation.

In addition to functional testing, performance testing was conducted to evaluate the system's capabilities under real operational conditions. The system was implemented on a drum tester machine at PT Astra Daihatsu Motor to evaluate its effectiveness in monitoring vibration levels on the pillow block bearing. The testing process covered hardware components, software functionality, LCD monitoring display, and the web-based monitoring platform. Data was collected periodically over 8 hours, with recordings taken at 1-minute intervals. The collected values were averaged hourly, resulting in a total of 8 hourly readings for further analysis.

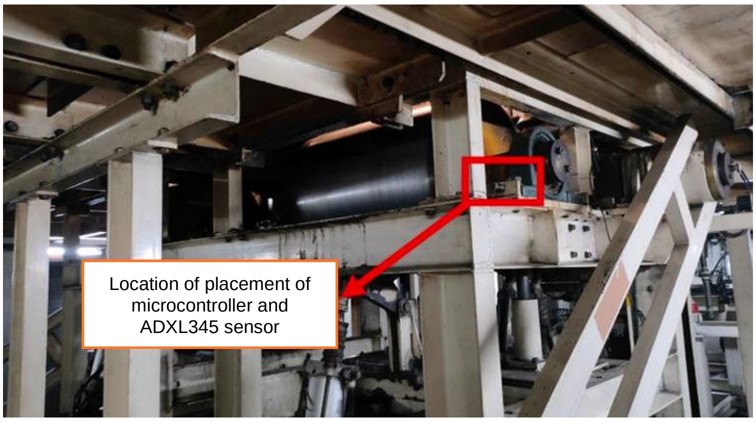


**Figure 4.** Installation location of the system

In this performance test, the sensor was placed on the test object (Fig. 4) and allowed to operate throughout the testing period to ensure the system's reliability in consistently reading and transmitting data. The test results showed that the data obtained from various measurement axes (X, Y, and Z) exhibited a stable trend without significant fluctuations that could indicate measurement inaccuracies (Fig. 5). This confirms that the system functions as initially designed and is capable of providing valid information regarding the machine's vibration conditions.

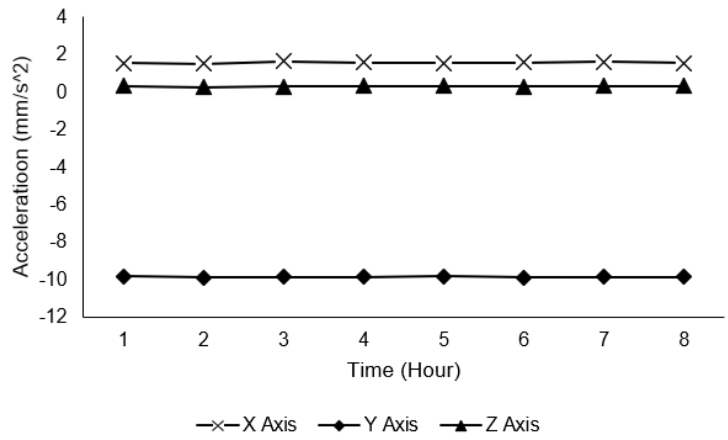


**Figure 5.** Measurement data result in the working condition

As a final step, verification was conducted on the displayed readings on both the LCD and the web-based monitoring system. Based on data analysis, no discrepancies were found between the data displayed on the LCD, the data stored in the MySQL database, and the data presented through the Grafana application. The dashboard display is shown in Fig. 6. This data consistency confirms that the system, both in terms of hardware and software, has operated optimally according to the specified requirements. Therefore, the developed monitoring system has been proven ready for industrial use, supporting real-time and accurate machine condition monitoring [18].

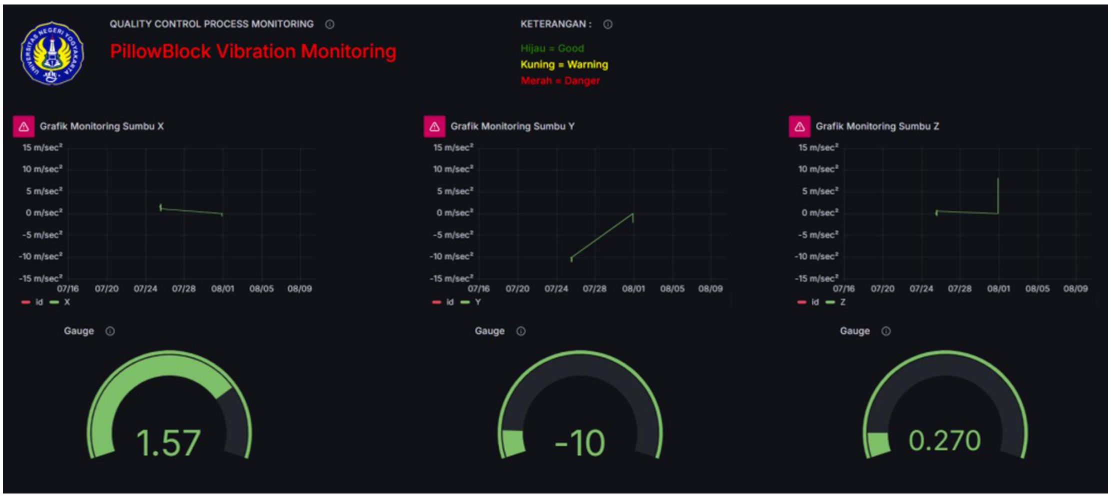


**Figure 6**. Measurement data results in working conditions on the dashboard interface

The implementation of this monitoring system has significantly improved workforce efficiency [19]. Prior to the system's deployment, pillow block inspections were conducted every two weeks. With the new system in place, inspections are now required only once a month, reducing the workforce needed from two workers to just one. Additionally, the inspection time has been drastically reduced from 20 minutes to just 1 minute, as workers can now check the data via a monitor without needing to go to the machine location. The improvement in system efficiency is presented in Table 5.

**Table 5.** Efficiency of the system usage

| No | Item | Before | | | After | | |
|---|---|---|---|---|---|---|---|
| | | Period | Workforce | Inspection time | Period | Workforce | Inspection time |
| 1 | Pillow block | 2 Week | 2 | 20 Min | 1 Month | 1 | 1 Min |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | Pillow block | 2 Week | 2 | 20 Min | 1 Month | 1 | 1 Min |
| 3 | Pillow block | 2 Week | 2 | 20 Min | 1 Month | 1 | 1 Min |
| 4 | Pillow block | 2 Week | 2 | 20 Min | 1 Month | 1 | 1 Min |

Thus, this system not only enhances workplace safety but also improves workforce efficiency through machine vibration monitoring.

### 3.3 Sensor Limitations and Noise Sources

There are several practical limitations to using the ADXL345 sensor in industrial settings, despite its reliability in detecting three-axis vibrations. Ambient noise, which can originate from nearby manufacturing or structural vibrations transmitted through the floor, is a significant concern. Vibrations from the surrounding environment can potentially degrade the sensor's performance in industrial environments when physical separation is inadequate. Electromagnetic interference (EMI) is another factor that affects measurement precision [20]. Because it uses Wi-Fi for communication, the ESP32 microcontroller is susceptible to occasional signal interference from adjacent radio-frequency (RF) sources such as routers, industrial transmitters, or wireless equipment. Nevertheless, it was noted during the system trials that EMI had a negligible effect on data transmission and integrity.

Thermal drift can also affect the sensor, particularly in hot environments or when exposed to constant heat from nearby machinery. The sensor's baseline readings can be subtly affected by long-term temperature swings, which could lead to less consistent measurements. This is why it's crucial to calibrate your device often to keep its accuracy over time. Additionally, applications that require the detection of micro-vibrations or extremely accurate diagnostics may not be well-suited to the ADXL345 sensor due to its 10-bit digital output resolution. The resolution is sufficient for most monitoring tasks, including detecting unusual vibration patterns in large mechanical components. However, it may miss more subtle changes that more sensitive sensors can detect.

The system design included multiple strategies to address and alleviate these constraints. Brackets designed to attenuate vibrations helped attach the sensor in an area where mechanical noise was minimal. To reduce transient noise and improve data clarity, the microcontroller's code also included signal smoothing techniques, such as averaging and filtering algorithms. In conclusion, the system is designed to allow for periodic calibration, ensuring that the sensor continues to provide accurate readings over time, regardless of changes in the surrounding environment.

## 4. Conclusion

This research successfully designed and implemented a vibration level monitoring system for drum tester machines using the ADXL345 sensor integrated with the ESP32 microcontroller and a web-based monitoring system. Based on the functional tests conducted, each system component operates efficiently by the specified requirements. The ESP32 microcontroller functions optimally with stable Wi-Fi connectivity, the ADXL345 sensor demonstrates high accuracy in measuring vibration acceleration, and the web-based monitoring system displays real-time data that is consistent with the readings shown on the LCD. Furthermore, the performance evaluation results indicate that the system can continuously monitor vibrations on the pillow block bearing for eight hours, with data recorded at one-minute intervals. The measurement results confirm the system's high reliability in detecting changes in machine vibration. Data presented in tables and graphs shows consistency between sensor readings and data stored in the MySQL database, with no significant discrepancies between the LCD readings and the web-based monitoring system.

The implementation of this monitoring system also enhances workforce efficiency. Previously, pillow block inspections were conducted biweekly; now, they are performed monthly, reducing the required workforce from two workers to one. Additionally, the inspection time has decreased significantly from 20 minutes to just one minute, as workers can now view the data on the monitor instead of physically inspecting the machine. This improvement in efficiency demonstrates that the developed system not only enhances workplace safety but also optimizes real-time monitoring of machine conditions. Thus, the vibration monitoring system, based on the ADXL345 sensor and ESP32 microcontroller, has proven effective in improving monitoring accuracy, workforce efficiency, and reliability in detecting changes in machine condition. The implementation of this system is expected to provide an innovative solution in the manufacturing industry, enhancing operational efficiency and machine safety.

Future research can enhance the current system by integrating machine learning (ML) algorithms to analyze vibration trends over time and predict potential failures before they occur. The inclusion of anomaly detection, pattern recognition, and adaptive thresholding through ML models can significantly improve predictive maintenance capabilities. Furthermore, expanding sensor types (e.g., higher-resolution accelerometers or multi-sensor arrays) and improving environmental shielding will enhance system robustness and diagnostic accuracy.

## Conflict of interest

The authors declare that they have no conflict of interest.

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