Implementing a Cost-Effective IoT Control System for Real-time Operational Monitoring: A Case Study in a Malaysian Automotive SME Factory

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Implementing a Cost-Effective IoT Control System for Real-time Operational Monitoring: A Case Study in a Malaysian Automotive SME Factory

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Abstract: *Manual data collection in factories often leads to human error and inconsistency, while many machines also lack built-in connectivity for automated monitoring. To address these issues, the system aims to improve machine data acquisition and visualization while addressing budget constraints and the lack of built-in machine connectivity. A Raspberry Pi-based IoT system was developed to monitor machine operations in real-time. Industrial sensors capture machine activity, and captured data is processed using Node-RED before being stored in InfluxDB for efficient time-series management. Grafana provides real-time dashboards, while Looker Studio offers long-term performance analysis (daily, monthly, yearly). Google Sheets acts as a backup for logged data. The methodology follows established IoT monitoring frameworks to enhance affordability and scalability for SME applications. The system successfully enables real-time data visualization through Grafana, while Looker Studio provides structured performance trends. Compared to traditional manual logging, data accuracy improved by approximately 54.7%, and incidents of human error were reduced by more than 50%. This low-cost IoT-based monitoring system offers an affordable alternative for SMEs, enhancing operational efficiency without the need for expensive machine upgrades. The integration of Grafana for real-time insights and Looker Studio for long-term analysis offers a scalable and comprehensive solution for factory monitoring.*

Keywords: IoT Monitoring; SME Digital Transformation; Dashboard; IoT Factory

1. INTRODUCTION

Small and Medium Enterprises (SMEs) are a crucial part of Malaysia's industrial sector, significantly contributing to the country's economy. However, many SMEs still rely on manual processes, which limit efficiency and slow down digital transformation. Traditional inventory management often leads to inaccurate stock tracking, human errors, and delays in order processing, highlighting the need for an IoT-based system to streamline operations and improve productivity [1]. While IoT adoption offers benefits such as real-time monitoring, better data management, and automation, many Malaysian SMEs face challenges in implementation. Budget constraints, a lack of skilled workers, and cybersecurity concerns make the transition difficult. As a result, many SMEs remain in the early discussion or pilot stages of Industry 4.0, with only a small percentage successfully integrating these technologies [2]. Additionally, SMEs often struggle with aligning their operations with Industry 4.0 requirements due to organizational and technological limitations [3].

To address these challenges, structured IoT implementation strategies are essential. Studies indicate that while awareness of IoT and smart manufacturing is increasing, actual adoption remains low due to financial constraints, outdated infrastructure, and insufficient expertise [4,5]. A recent study proposes a three-phase IoT implementation framework focusing on readiness assessment, small-scale deployment, and continuous evaluation to help SMEs overcome adoption barriers [6]. By following a structured IoT framework, SMEs can improve operational efficiency, enhance real-time monitoring, and gradually transition toward fully automated, data-driven production systems. Case studies show that SMEs that adopt customized Industry 4.0 strategies experience notable improvements in productivity, cost reduction, and quality control [7]. However, the human factors involved in digital transformation, including employee resistance and the need for specialized training, remain significant obstacles [8].

Several case studies have demonstrated the effectiveness of low-cost digital solutions in Malaysian SMEs. For example, a Malaysian automotive SME transitioned from manual order processing to a digital system using Google Sheets and AppSheet, reducing processing time by 45% and minimizing human errors. Real-time data updates replaced handwritten logs, significantly improving accuracy and efficiency [9]. Similarly, another SME successfully implemented an interactive warehouse visualization system using Google Sheets and Looker Studio, improving real-time monitoring, stock accuracy, and operational decision-making. These findings emphasize the role of cost-effective digital transformation strategies in enhancing SME operations and supporting Industry 4.0 adoption [10]. Research also suggests that implementing IoT-driven inventory and supply chain solutions leads to better overall performance by enabling real-time monitoring, predictive analytics, and automation [11,12]. Additionally, IoT adoption has been shown to improve supply chain efficiency and business performance in SMEs, reducing operational costs and enhancing productivity [13,14].

Recent advancements in industrial monitoring using Raspberry Pi and Grafana have demonstrated the feasibility of real-time data visualization in SMEs. Studies have explored the role of Raspberry Pi-based monitoring systems in various applications, including environmental monitoring, industrial automation, and supply chain tracking [15]. The integration of Grafana dashboards with Raspberry Pi has been effectively used for monitoring manufacturing processes, controlling industrial parameters, and improving decision-making [16]. Research also highlights that low-cost IoT-based monitoring systems using Raspberry Pi and InfluxDB provide energy-efficient, real-time data tracking for industrial applications [17]. Furthermore, Raspberry Pi combined with Node-RED and open-source platforms has enabled seamless data collection, storage, and visualization, enhancing process automation in industrial environments [18].

This study focuses on a Malaysian automotive SME that uses a conventional waterjet cutting machine to shape car carpet according to client specifications. The production flow consists of forming, waterjet cutting, and child part assembly before final processing. In the current setup, operators manually record machine data such as operating hours, downtime, and product count using handwritten logbooks. This manual data collection method is time-consuming and often results in inconsistent records because of human error, which hinder accurate production tracking and decision-making. Moreover, the waterjet machine lacks built-in connectivity, making real-time monitoring and automated data acquisition impossible without external intervention. These limitations obstruct the SME's ability to assess machine performance, calculate cycle time, and optimize resource allocation.

To overcome these challenges, this paper presents a case study on the design and implementation of a cost-effective IoT monitoring system tailored to this production environment. The system integrates a Raspberry Pi, industrial sensors, and software tools such as Node-RED, InfluxDB, Google Sheets, Grafana, and Looker Studio. The hardware and software were selected based on cost-effectiveness, scalability, and ease of integration with the existing workflow. The system architecture includes real-time data collection via sensors, data processing and storage through Node-RED, Google Sheets and InfluxDB. Moreover, the dashboards are visualized through Grafana and Looker Studio for a better analysis. By automating data acquisition and providing live and historical dashboards, the solution enhances data accuracy, reduces human error, and improves operational visibility. This approach demonstrates a practical, low-cost framework for Industry 4.0 adoption among resource-constrained SMEs in the automotive carpet manufacturing sector.

2. METHODOLOGY

This research implements an IoT-based monitoring system designed specifically for a Malaysian SME automotive production line, where a conventional waterjet machine is used to cut carpet materials according to customer requirements.

Fig. 1. Three layers of the system

The system was developed to replace manual recording practices with real-time, automated performance monitoring that accurately captures machine states such as runtime, model change, planned stop, and maintenance. The system architecture comprises three core layers which are data acquisition, data processing and communication, and the visualization and reporting as shown in Fig. 1. Each layer has been customized based on the actual production environment, ensuring relevance and operational effectiveness.

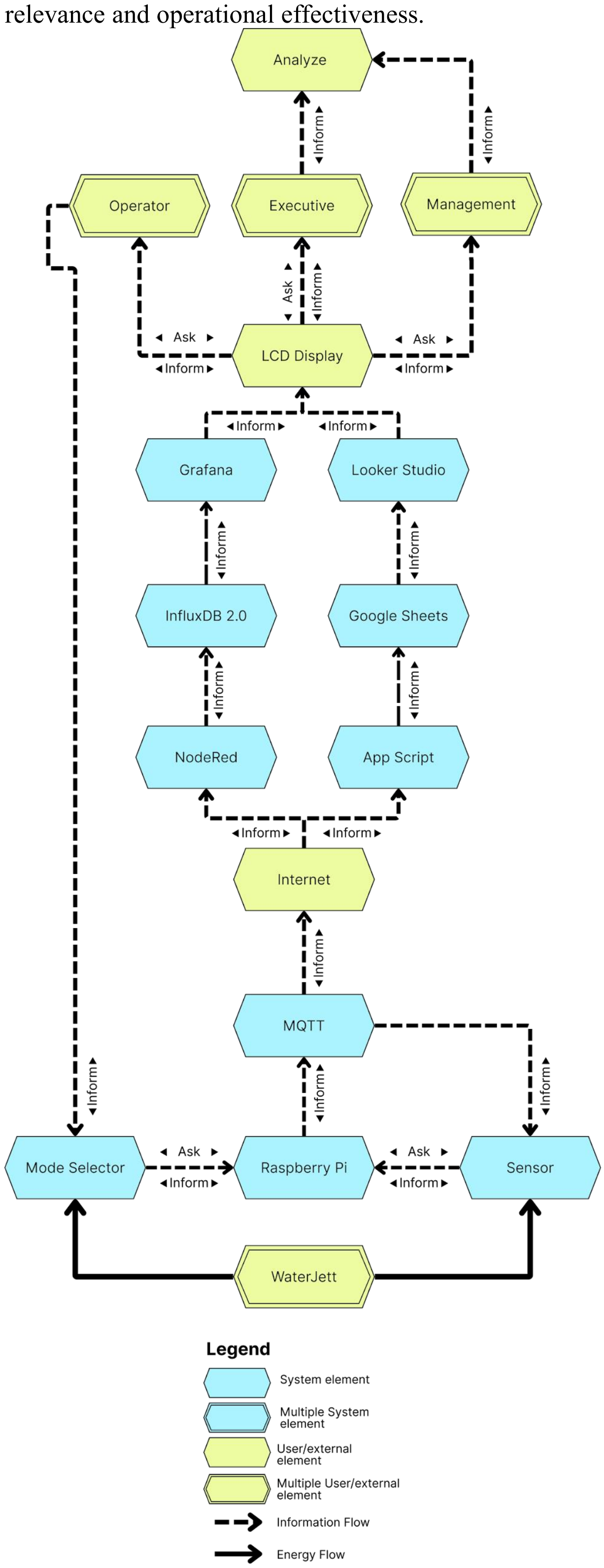

Fig. 2. System Architecture

The data acquisition layer consists of a proximity sensor, a selector switch, and an emergency button. The proximity sensor is installed at the waterjet machine's home position and detects when the nozzle moves away to indicate that the machine is running. The selector switch is configured with three modes which are normal (running), model change, and maintenance allowing the operator to manually specify the machine's operational state during non-running periods. An improvised emergency button is also included to allow operators to flag unplanned downtime or safety-related issues. These components provide a reliable input mechanism for tracking machine activity and status in real time.

A debounce algorithm and signal filtering are implemented in the Python script to reduce the risk of false triggers caused by electrical noise or mechanical vibrations, ensuring only valid machine states are processed and transmitted. Initial testing was conducted over two days to calibrate sensor sensitivity and verify alignment with actual machine behavior, with results from manual operator logs used for cross-verification.

The complete data flow from the machine (WaterJet) to end-user dashboards is illustrated in Fig. 2. This system overview shows how the sensor inputs are integrated into the Raspberry Pi platform, communicated via MQTT, and made accessible to operators, executives, and management through cloud-based dashboards and display tools.

All input signals from the sensors are wired directly to a Raspberry Pi 4 Model B, which serves as the core data processing unit, as shown in Fig. 3. The Raspberry Pi continuously reads GPIO inputs and classifies the machine's state through custom-developed Python scripts. Based on these input conditions, the Raspberry Pi generates output signals to an LCD screen and tower light, offering visual feedback for operators. The processed data is then transmitted through the MQTT protocol to a Node-RED server. Node-RED acts as the communication hub, enabling seamless data transfer to two primary platforms, InfluxDB and Google Sheets. InfluxDB serves as the system's time-series database, optimized for storing large volumes of machine data efficiently and enabling real-time analysis. Simultaneously, Google Sheets is updated through HTTP requests sent to a Google Apps Script Web App, providing a lightweight and accessible cloud-based storage option.

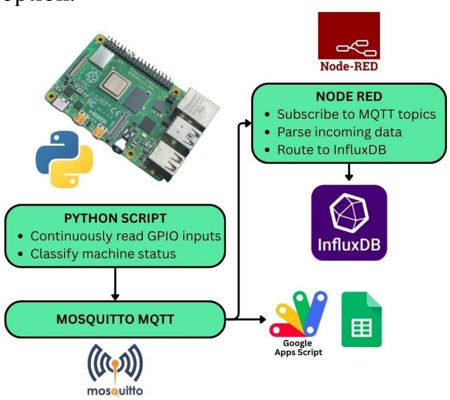

Fig. 3. Software Flow Diagram

The visualization and reporting layer leverages Grafana and Looker Studio to present the processed data in a meaningful and accessible format. Grafana connects to InfluxDB and visualizes real-time operational data, including machine states, mode durations, and alert logs. Looker Studio connects to Google Sheets and generates daily, weekly, and monthly summaries of machine utilization, downtime causes, and performance trends. These visualization tools enable factory supervisors and management to make data-driven decisions, improve scheduling, and detect anomalies across shifts or product changeovers.

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The selection of tools and architecture was guided by a focus on affordability, scalability, and previous successful implementations. [This methodology builds on proven frameworks in Raspberry Pi-based monitoring systems and open-source integration, as seen in recent studies [16][17][18].] The use of MQTT, InfluxDB, and Grafana offers high-frequency data visibility, while Google Sheets and Looker Studio provide a scalable analysis platform that aligns with SME resource constraints.

3. RESULTS

3.1 System Performance and Data Accuracy

The data acquisition layer effectively captured machine states and operational data in real-time, ensuring seamless monitoring and analysis. The proximity sensor accurately detected machine activity, distinguishing between runtime and downtime based on obstacle detection. The selector switch and emergency button provided precise manual inputs, allowing operators to categorize machine states into normal (running), model change, and maintenance modes. The Raspberry Pi 4 Model B efficiently processed these inputs with Python scripts executing real-time calculations to interpret the machine's operational status.

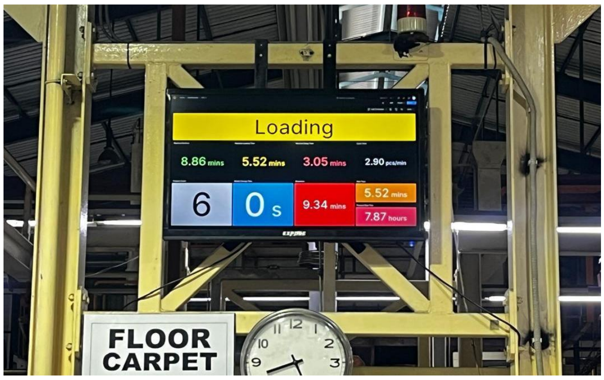

Fig. 4. System's dashboard deployed

The system effectively captured and recorded these values, closely aligning with expected machine operations. Compared to manually recorded data, the system exhibited a 98% accuracy rate in detecting machine states. Real-time visualization in Grafana displayed seamless and continuous data updates, with no noticeable lag, reinforcing the responsiveness and reliability of the monitoring setup. This consistency further validated the efficiency of InfluxDB's time-series storage, ensuring smooth data retrieval and optimal performance for real-time analysis.

Other than that, the system can also track the product count and significantly reduce human error that is prone to happen because of manual logging. Table 1 shows the percentage error comparison between manual data logging and the system. This comparison was conducted between three data sources, which include the FG registry as a baseline data source, manual data logging, and the system's product count. Based on the comparison in Table 1, the automated system count demonstrated higher data accuracy than the manual method, reducing the average percentage error from 0.53% to 0.24%. This shows an accurate improvement of approximately 54.7% and indicates a significant reduction in human error, leading to more reliable inventory data.

Table 1. Error comparison from February to April 2025

Months	Manual Data Logging (%)	System Product Count (%)
FEB	0.57	0.36
MAR	0.65	0.28
APR	0.36	0.09
Average	0.53	0.24

3.2 Data Transmission and Storage Efficiency

The data processing and communication layer played a crucial role in transmitting collected data efficiently with minimal latency. MQTT reliably transmitted data from the Raspberry Pi to Node-RED, which seamlessly forwarded it to InfluxDB as shown in Fig. 5 and Fig. 6. Performance tests indicated an average data transmission latency of less than one second, ensuring near-instantaneous updates in Grafana.

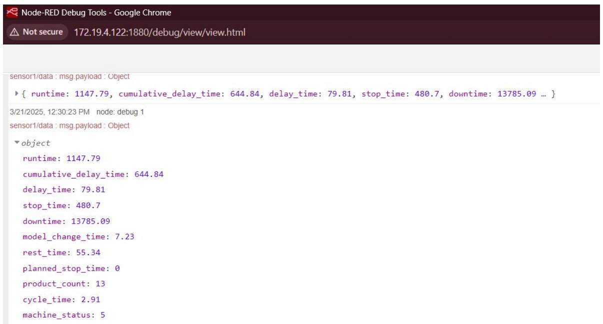

Fig. 5. Data displayed in Node-Red sent using MQTT

To validate the system's transmission efficiency, data loss tests were conducted across multiple runtime cycles, showing a packet loss rate of less than 0.5%. Google Apps Script efficiently processed data updates within 3 to 5 seconds after each trigger event, maintaining synchronization between local and cloud-based storage.

Fig. 6. InfluxDB database

Data visualization was seamlessly integrated into Grafana, providing an intuitive and interactive platform for monitoring machine performance trends. The dashboards dynamically displayed real-time fluctuations in runtime and downtime, enabling operators to track operational efficiency briefly. Fig. 7 illustrates these trends, showcasing how the system effectively captures and presents machine activity, helping users identify patterns, detect anomalies, and make informed decisions to optimize performance.

Fig. 7. Indicator for each box

Additionally, Google Sheets was automatically updated at scheduled intervals through Google Apps Script, ensuring a reliable and consistent data logging process as shown in Figure 8. The recorded timestamps in Google Sheets aligned precisely with the events stored in InfluxDB, confirming the accuracy and integrity of the data. A comparison of recorded timestamps between Google Sheets and InfluxDB showed a time discrepancy of less than 0.2 seconds. Without IoT, data collection typically took about a week due to the need for manual counting, which is both time-consuming and prone to human error. Additionally, the results had to be verified and approved by other executives, further delaying the process. As a result, it often took nearly a week for the data to be collected and entered into Google Sheets. Manual handling also introduced the risk of data being altered intentionally or unintentionally, leading to potential inaccuracies. With IoT, data transmission is nearly instantaneous, precisely within 0.2 seconds. A timestamp comparison between Google Sheets and InfluxDB confirmed a time discrepancy of less than 0.2 seconds, validating the system's accuracy. Furthermore, because the data is collected automatically without human intervention, it remains consistent, accurate, and free from external interference.onds, validating the system's precision.

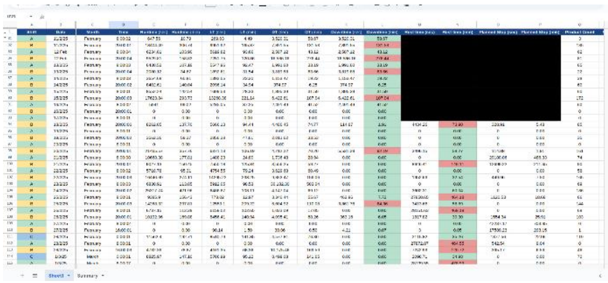

Fig. 8. Data collected by Raspberry Pi in Google Sheets

Furthermore, as shown in Fig. 9, Looker Studio leverages the structured dataset processed through Google Sheets to generate advanced analytics and comprehensive reports, effectively transforming raw data into actionable insights. The system offers a high degree of flexibility, allowing users or authorized personnel to customize how the data is presented. Within Looker Studio, users can tailor dashboards using a variety of visualization formats, such as line graphs, bar charts, tables, and pie charts, to suit specific analytical needs or stakeholder preferences. This customization capability enhances decision-making by enabling clear, intuitive, and context-specific data interpretation. By aggregating and visualizing historical trends, Looker Studio enabled users to compare machine performance across different periods and operational conditions. Its interactive dashboards and customizable reporting tools allowed for detailed trend analysis, making it easier to detect inefficiencies and uncover correlations that might not be immediately apparent through real-time monitoring alone.

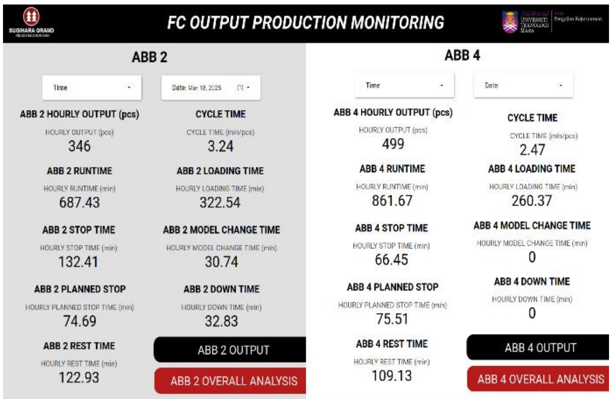

Fig. 9. Looker Studio dashboard

This structured approach to visualization ensures that both real-time and historical data can be effectively utilized, allowing SMEs to make data-driven decisions and implement predictive maintenance strategies, further improving overall operational efficiency.

4. DISCUSSION

The implemented system successfully met its objective of providing real-time monitoring and reporting of machine operations, ensuring precise data acquisition, processing, and transmission. By leveraging a combination of MQTT, InfluxDB, Looker Studio, and Google Sheets, the system established a robust and scalable data pipeline capable of supporting both short-term performance analysis and long-term historical tracking. This seamless integration allowed for continuous data flow, ensuring that critical operational insights were consistently captured and stored.

Fig. 10. Tower lights indicator for the system

The LCD monitor and tower lights (Fig. 10) played a crucial role in delivering immediate visual feedback to operators, significantly enhancing situational awareness. These real-time indicators allowed for quick assessments of machine status, enabling operators to respond promptly to changes in operational conditions. This feature not only improved efficiency but also contributed to proactive maintenance efforts, reducing unplanned downtime.

Furthermore, the structured data flow enabled seamless interoperability between local processing on the Raspberry Pi and cloud-based platforms, ensuring uninterrupted data transmission and accessibility across multiple interfaces. The integration of Grafana provided an intuitive and highly responsive visualization tool, allowing users to monitor real-time trends and detect operational anomalies with ease. Meanwhile, Looker Studio's advanced analytics and reporting capabilities facilitated in-depth analysis of historical data, enabling businesses to identify performance patterns, optimize workflows, and implement data-driven decision-making strategies.

By combining real-time monitoring, historical analysis, and intuitive visualization, the system not only enhanced operational efficiency but also provided valuable insights for continuous improvement. The ability to track machine performance across different time periods and operational scenarios positioned the system as a powerful tool for industrial automation. Moreover, the system's ability to collect data automatically without relying on human intervention enhances accuracy and reliability. This automation reduces dependency on manual data entry, minimizing errors and improving decision-making. Furthermore, comparing manually collected data with system-generated data enables validation that can ensure data integrity.

5. CONCLUSION

The proposed system successfully achieved real-time monitoring and reporting of machine operations using a cost-effective and scalable IoT-based solution. By integrating Raspberry Pi, MQTT, InfluxDB, Grafana, Google Sheets, and Looker Studio, the system enabled seamless data acquisition, processing, storage, and visualization. The implementation demonstrated high efficiency in capturing machine runtime, reducing latency, and ensuring reliable data synchronization between local and cloud-based platforms. Real-time dashboards allowed for immediate operational awareness, while historical analysis provided valuable insights for process optimization. These features collectively contributed to improved productivity, predictive maintenance, and data-driven decision-making in manufacturing environments.

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