Semarak International Journal of Agriculture, Forestry and Fisheries

Journal homepage:
https://semarakilmu.my/index.php/sijaff/index
ISSN: 3030-5667

Real-Time Revolution: Interactive Machines Monitoring System for Palm Oil Farm

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ARTICLE INFO

Article history:
Received 10 December 2024
Received in revised form 5 January 2025
Accepted 14 March 2025
Available online 31 March 2025

Keywords:
Real-time monitoring; machine tracking; farm management; operational efficiency; data visualization; data collection

ABSTRACT

The agricultural sector, particularly large-scale operations like palm oil plantations, increasingly demands real-time tracking of operational machinery. Traditionally, monitoring has relied heavily on manual logs and records to track machine schedules and availability due to the dense tree canopy in the farm, which limits Internet access. However, in response to the demands of the digital age, there is a growing shift towards adopting IoT technology for real-time monitoring. This study presents the development of a real-time machine tracking and monitoring system tailored for palm oil plantations. Leveraging IoT technology, the system enables the real-time tracing and monitoring of operational machinery routes and movements. Machines are equipped with mounted sensors for remote tracking, which transmit data to a centralized server for processing. This infrastructure provides enhanced accessibility to machine locations and other related information. The data collected by the sensors is processed and presented through a user-friendly interface. This interface features an interactive map, allowing staff to easily visualize machine locations. Additional features include notifications for prolonged machine inactivity and status updates, offering actionable insights. By converting complex sensor data into an intuitive visual format, the system improves decision-making processes and operational efficiency. In near future, the system is designed to be adaptable for regions with limited Internet connectivity, ensuring its applicability across various areas within farm fields. Our contribution aims to optimize asset management, ultimately supporting the sector's focus on improving overall farm efficiency.

1. Introduction

The agricultural sector, especially in large-scale operations like palm oil farms, increasingly relies on operational machines for day-to-day activities such as harvesting, transportation, and maintenance. However, traditional methods of monitoring these machines, which often involve manual logs and records, are inefficient and prone to errors. These practices make it challenging to track machine schedules and availability, leading to delays in operations, increased costs, and

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https://doi.org/10.37934/sijaff.4.1.3045b

reduced productivity. Caicedo *et al.,* [1] found that manual tracking methods result in 30% higher operational costs due to inaccuracies and delays.

In response to the demands of the digital era, there is a growing expectation for palm oil farms to adopt real-time monitoring solutions to enhance operational efficiency. The integration of Internet of Things (IoT) technology enables real-time tracking and monitoring of operational machines, ensuring that data from machines is accurately transmitted to reader devices. This connectivity is crucial for tracing machine routes and movements, as well as for optimizing the utilization of resources. Furthermore, IoT-based systems collect real-time location information and transmit it to centralized servers, where the data is processed and displayed on user-friendly interfaces, improving accessibility and decision-making. The effectiveness of these systems relies on precise sensor data. Dadios *et al.,* [2] highlight the importance of accurate sensor technologies in ensuring reliable data transmission and positioning, which is essential for real-time applications like monitoring farm machinery. Accurate data collection ensures these systems provide actionable insights, optimizing farm operations and resource management. The significance of centralized and digitized data management processes is emphasized in various studies. For example, Samayel *et al.,* [3] highlight the challenges caused by the reliance on paper-based records in the educational system of Bangladesh. These outdated methods lead to inefficiencies in data handling, making effective management difficult. Their development of a centralized school management system using a distributed database demonstrates how transitioning to digitalized systems can address such inefficiencies and improve operational outcomes.

For palm oil farms, implementing such systems provides numerous advantages. Machines equipped with strategically placed sensors can send accurate data on their IDs, locations (latitude and longitude), and operational statuses. Ouafiq *et al.,* [4] underscore the importance of centralized data management in the agricultural sector. Their research identifies how manual processes in farm machinery management can hinder efficiency, advocating for a shift to centralized, digitized systems to streamline data management and optimize resource allocation. This eliminates the need for manual tracking methods, which are prone to human error. Additionally, the collected data is visualized on interactive maps, allowing farm staff to monitor machine locations and statuses efficiently. Notifications are generated when machines remain active for extended periods or undergo status changes, enabling prompt responses and better decision-making. According to Lauren [5] push notifications are an essential marketing tool for anyone. It’s the best way to connect with your users, delivering important and time-sensitive messages.

Despite these advancements, many palm oil farms still rely on traditional methods due to challenges such as limited connectivity, lack of tailored solutions, and insufficient integration of IoT systems. Additionally, existing research often focuses on general agricultural applications without addressing real-time monitoring processes, which are hindered by the unique challenges of palm oil plantations, such as dense tree canopies and large-scale operations. This creates a research gap in developing systems specifically designed for this context.

This study aims to develop a Real-Time Machine Tracking and Monitoring System tailored for palm oil farms. The system uses IoT technology to provide real-time data on machine locations and statuses, which is processed and displayed on an intuitive interface. By replacing manual tracking methods with automated solutions, the system enhances accessibility to machine data, reduces manual effort, and improves farm productivity by facilitating quicker and more informed decision-making. A study by Pandey *et al.,* [6] highlighted that visualizing machine locations on a map can reduce the time taken to make operational decisions by up to 30% compared to non-visual methods.

2. Methodology

The development of the Real-Time Machine Tracking and Monitoring System for palm oil farms follows a structured methodology aimed at achieving an effective and user-friendly system. According to Krishnamurthy, [7] Agile refers to a collection of software development methods which share a common requirement in seeking the client's direct involvement when providing solutions. Agile emphasizes iterative development, flexibility, and regular feedback from stakeholders. Scrum also one of the more popular frameworks for various reasons which this report shall highlight. However, Sutherland [8] stated, scrum is not a defined process but an experiential guide to project management. By Schwaber, [9] the scrum team is a cross-functional group in that technical roles are not clearly defined but instead members of the team work collectively to complete a task or 'sprint'. This study employs the Agile Scrum methodology (Figure 1) to ensure that the system evolves in line with user needs and technological requirements. The methodology comprises six phases: scope definition, product backlog creation, sprint planning, sprint execution, sprint review, and sprint retrospective.

2.1 Methodological Framework

The first phase, scope definition, involves clarifying the project's objectives, functionalities, and technical requirements. This was achieved through discussions with stakeholders, including farm staff and farm managers, to ensure that the system addressed their needs. The scope was narrowed to focus on key functionalities such as real-time machine tracking, location-based visualization, and machine status monitoring. Nivaan *et al.,* [10] study focuses on smart bus transportation systems in Indonesia, highlighting the absence of a mobile-based bus tracking system and proposing a wireless sensor network for real-time tracking and monitoring of buses. Their approach integrates GPS technology and supporting sensors to provide accurate, real-time bus position information and route recommendations. Therefore, during this phase, the technical requirements were also evaluated, including the need for GPS data and the integration of mapping tools like Google Maps API like Hussein and Rizi [11] research underscores the usability benefits of interactive map features in facilitating exploration across different regions.

Once the scope was defined, the project entered the product backlog creation phase. In this phase, a prioritized list of tasks was developed. The backlog included high-priority features, such as the design of a user-friendly dashboard and the implementation of real-time data processing. Medium-priority tasks involved adding notifications for prolonged machine activity and developing an efficient database structure to store and retrieve tracking data. Lower-priority tasks, like advanced data analytics and reporting features, were planned for later stages. This structured backlog provided a clear roadmap for development, ensuring that critical features were prioritized while leaving room for additional functionalities.

The next phase, sprint planning, focused on organizing tasks into manageable units for execution over two-week sprints. Each sprint had specific goals, such as completing a particular section of the user interface or integrating a sensor for real-time tracking. Sprint planning involved breaking down complex tasks into smaller, achievable objectives, assigning roles, and setting timelines. This phase also emphasized communication and coordination among team members to ensure that everyone was aligned on the goals for each sprint.

The sprint execution phase involved active development of the system. During this phase, the user interface was designed using Figma, ensuring it was both functional and easy to use. The interface was designed to allow users to view machine locations in real time, select machine IDs, and receive notifications about machine status changes. Data from IoT sensors, such as GPS coordinates and operational status, was captured and processed using edge computing. This aligns with the proposal by O'Grady *et al.,* [12] to utilize edge computing to benefit rural farming areas by processing data locally. This local processing minimized latency and ensured faster updates, which was critical for real-time monitoring [13]. In parallel, the system's backend, including databases such as Firebase, was set up to store and manage machine data.

As each sprint concluded, the project entered the sprint review phase. During this phase, completed features were demonstrated to stakeholders for feedback. The review sessions focused on ensuring that the system met user expectations and requirements. Feedback was gathered on aspects such as the usability of the interface, the accuracy of the real-time location tracking, and the timeliness of the notifications. This feedback was invaluable for refining the system and making adjustments for future iterations.

Finally, the sprint retrospective phase allowed the development team to reflect on the sprint's outcomes. In this phase, the team discussed what went well, what challenges were encountered, and how processes could be improved for the next sprint. Lessons learned from each iteration were documented, ensuring continuous improvement throughout the development cycle. This phase fostered a culture of accountability and collaboration, driving the team to enhance the system in each successive sprint.

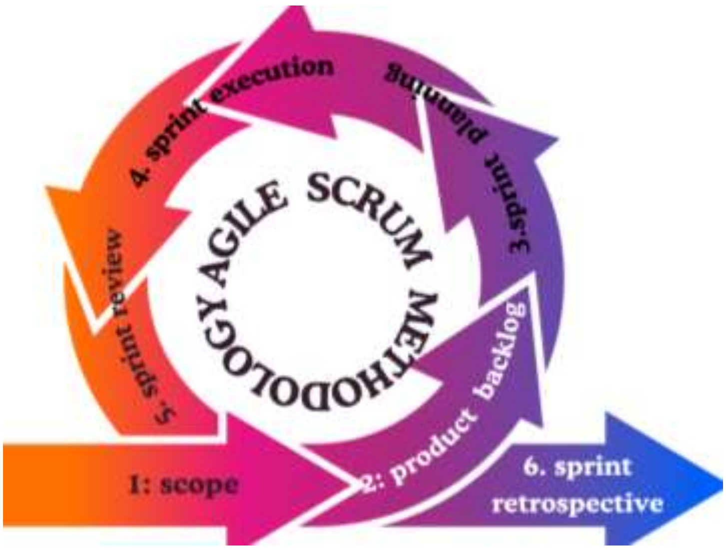

Fig. 1. Agile scrum methodology process

2.2 Tools and Technologies

The development of the Real-Time Machine Tracking and Monitoring System utilized a variety of tools and technologies to address the unique challenges of monitoring and managing machines within the palm oil farm environment. These tools were carefully selected to ensure seamless integration, efficient real-time data collection, and processing, as well as an intuitive user interface for ease of use. The following table (Table 1) outlines the key tools and technologies used in the system, along with their descriptions and roles in the overall architecture.

Table 1
List of tools and the descriptions

Tool	Description
Flutter	Cross-platform development framework used to design an intuitive and responsive interface.
Firebase	Real-time database and authentication service for secure and efficient data handling.
Google Maps API	Provides mapping capabilities to visualize machine locations accurately.
Figma	Prototyping tool for creating user-friendly interface designs.
VS Code	IDE used for coding and debugging system functionalities.

2.3 Implementation Challenges and Mitigation Strategies

The implementation of the Real-Time Machine Tracking and Monitoring System for palm oil farms posed several challenges, which were addressed through thoughtful design and strategic solutions. Financial constraints were a primary concern, as implementing IoT-based systems in large-scale plantations can be costly. To mitigate this, the system utilized open-source tools and free-tier services during development, ensuring cost-effectiveness without compromising functionality. Additionally, the system was designed with a modular architecture, allowing incremental deployment to spread expenses over time, making it more accessible to farms with limited budgets. Another significant challenge was the varying levels of technological literacy among farm staff. Many workers had limited experience with digital tools, necessitating an interface that was simple and intuitive. The system's design prioritized usability, incorporating visual aids such as color-coded markers, icons, and straightforward navigation to guide users. Complementary training programs and detailed user manuals were developed to help staff quickly adapt to the system, ensuring smooth adoption.

Connectivity issues in remote plantation areas present significant challenges, as many regions experience intermittent or weak Internet access, potentially disrupting real-time monitoring. To address this, the system incorporates edge computing to process data locally, reducing dependency on Internet connectivity. However, this approach requires further study and is not the primary focus of this paper. Instead, we concentrate on optimizing data readability from sensors to ensure it is easily understood by farm workers, facilitating better analysis and aiding farm office management. Therefore, the system is designed to be practical, scalable, and user-friendly, ensuring its successful deployment and long-term usability in palm oil farm.

2.4 Data Collection and Processing

Data collection is a central component of the system. IoT sensors installed on the machines capture real-time data, including machine IDs and GPS coordinates (latitude and longitude). This data is transmitted to a centralized server, where it is stored and processed for analysis. While the system relies on a server for processing, data synchronization mechanisms ensure that information is up-to-date, even during periods of intermittent connectivity. Once the connection is restored, the system ensures that data collected during offline periods is updated to the central database, maintaining consistency across the system.

This data collection process aligns with the principles discussed by Dasig, [14] who emphasizes the importance of effective data collection and processing in precision agriculture. By integrating real-time data collection with interactive dashboards, it highlights how this approach enables actionable insights into machine activities and environmental conditions Similarly, Seif [15] emphasizes the value of geospatial data collection techniques, such as remote sensing and geocoding, which align with the system's use of GPS data to track machine locations and support operational efficiency.

Figure 2 visually represents how data is captured from the centralized server, showing the real-time latitude and longitude coordinates of machines as processed and stored in the database. The data is transmitted from the IoT-enabled sensors on the machinery to the server, ensuring that real-time machine data is accurately recorded and available for visualization and further analysis.

```
pi@raspberrypi:~ $ python gps_send.py
Latitude=3.9330418333333332 and Longitude=102.382892
Data sent
Latitude=3.9330375 and Longitude=102.382888
Data sent
Latitude=3.9330308333333335 and Longitude=102.3829171666667
Data sent
Latitude=3.9330249999999998 and Longitude=102.3829406666667
Data sent
Latitude=3.933019333333333 and Longitude=102.38296
Data sent
Latitude=3.933015 and Longitude=102.3829771666666
Data sent
Latitude=3.9330108333333333 and Longitude=102.3829855
Data sent
Latitude=3.933011666666667 and Longitude=102.383002
Data sent
Latitude=3.9330146666666668 and Longitude=102.3830216666666
Data sent
Latitude=3.9330166666666666 and Longitude=102.383013
Data sent
Latitude=3.9330196666666666 and Longitude=102.3830106666666
Data sent
```

Fig. 2. Data collection for latitude and longitude coordinates

2.5 Agile Scrum Methodology in Action

The Agile Scrum methodology played a key role in ensuring the project remained flexible and responsive to changing user needs and technological demands. According to Peek, [16] Agile Scrum is valued for its ability to foster high-end collaboration and efficiency, making it particularly effective for project-based work. This aligns with the project's focus on adaptability and continuous improvement to meet evolving requirements. The iterative approach, structured around two-week sprints, allowed the system to be continuously developed and refined. With regular feedback loops from stakeholders, issues were identified early, enabling the development team to address them swiftly. Each sprint delivered incremental functionality, providing stakeholders the opportunity to interact with the system, offer feedback, and influence the direction of future sprints. This iterative cycle of planning, execution, review, and reflection ensured that the final product was closely aligned with user expectations and requirements.

The system architecture, designed to support this agile development process, centres around a centralized server that acts as the backbone for data collection and analysis. Initially, data is collected and transmitted to the server, where it is processed, stored, and made accessible to users through an interactive dashboard. This architecture supports continuous, real-time analysis of machine data, enabling users to make informed decisions based on up-to-date information. By focusing on the server as the core component, the system efficiently manages large volumes of data while ensuring scalability and robust performance.

This combination of Agile Scrum methodology and a centralized server architecture allowed for a dynamic and adaptive development process, delivering a solution that met both technical and user-driven requirements.

2.6 Interface System Design

The interface system for the farm machinery monitoring project incorporates advanced visualization techniques and centralized data management, ensuring accessibility, usability, and operational efficiency. By transforming raw machine data, such as latitude and longitude coordinates, into intuitive maps and dashboards, the system provides actionable insights to enhance decision-making processes. This aligns with established best practices for data visualization and information hub frameworks, which emphasize simplifying complex data for better comprehension. As Tufte [17] explains, "Above all else, show the data," emphasizing the importance of presenting information in a straightforward and uncluttered manner. He further notes that "good design is clear thinking made visible," underscoring the role of thoughtful visualization in improving understanding and supporting decision-making. Similarly, Tisljaric [18] highlights the importance of translating geographical coordinates into user-friendly visual formats. By leveraging tools like Python and Open Street Maps, raw sensor data can be transformed into interactive visualizations, enabling farm staff to monitor machine locations in real time with precision.

The design uses orange, white, and black as the primary colours. Orange conveys energy and alertness, essential for highlighting important information. It is vibrant and energetic, associated with enthusiasm, excitement, and warmth, making it effective for drawing attention Juby, [19]. White ensures a clean and uncluttered background that enhances readability. In Western cultures, white represents purity and simplicity, offering a neutral space that does not overwhelm the viewer Juby, [19]. The black sidebar creates a clear visual distinction, drawing attention to navigation elements. As Mark [20] explains, dramatically contrasting colors, such as black against a lighter background, help prioritize important elements and guide the viewer's focus within the design. Additionally, blue and red map markers are employed to differentiate machine types, providing a quick visual reference for farm staff to distinguish between operational categories.

The system’s dashboard functions as an information hub, centralizing machine tracking and operational data. By consolidating data into a single, accessible platform, the system allows farm staff to retrieve, update, and visualize information in real time. This digitization reduces errors, streamlines workflows, and supports better resource allocation and operational responsiveness.

The integration of real-time tracking and location sharing further enhances the system’s functionality. Like WhatsApp’s live location feature and Apple’s Find My app, the project enables farm staff to monitor the precise locations of machinery (Figure 3). Blue and red markers on an interactive map reflect machine statuses and types, similar to Apple’s real-time device tracking. This feature allows staff to quickly assess the current state of operations, facilitating immediate responses to potential issues, such as machinery overuse or misplacement.

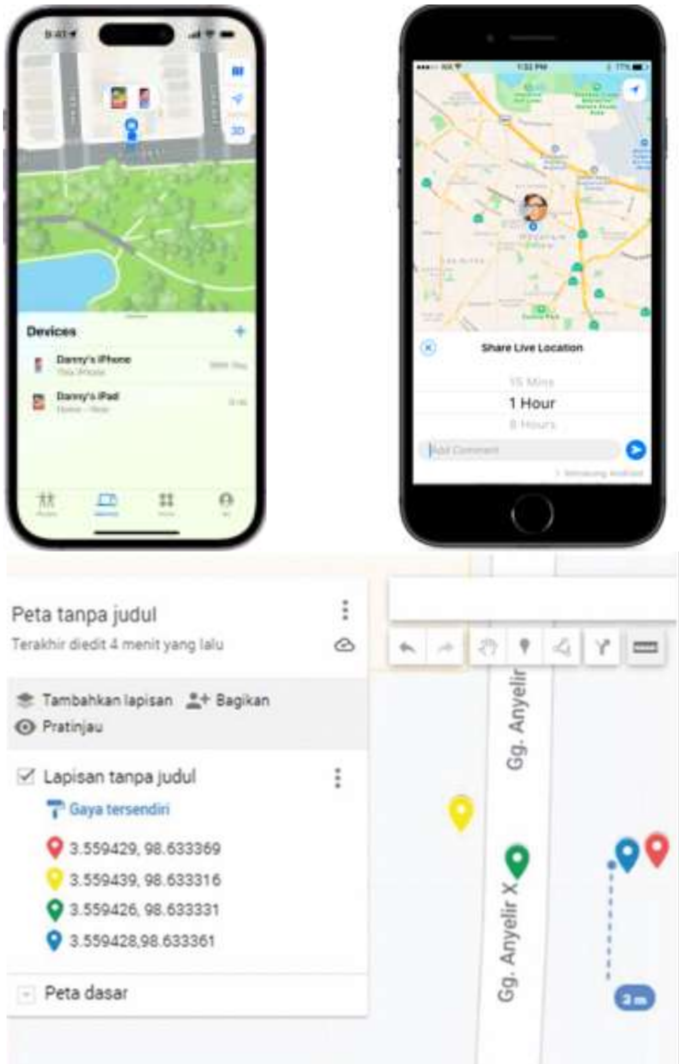

Fig. 3. Examples of system location monitoring interface

Guevara *et al.,* [21] further explore the application of dashboards in a global flight tracking system, demonstrating how real-time flight data can be easily comprehended through such visual displays. This approach not only improves decision-making but also enhances situational awareness, a principle that is directly applicable to the real-time monitoring of farm machinery. By using dashboards to visualize operational data, farm staff can gain a clearer overview of machine statuses, enabling more informed decisions and quicker responses to operational challenges.

To support seamless data handling, the project employs SQLite3 databases, renowned for their lightweight architecture and efficient management of relational data, as highlighted by Alonso *et al.,* [22]. SQLite3's embedded nature ensures reliable storage and retrieval of sensor data, making it ideal for IoT-based systems with intermittent connectivity. This choice enables the system to operate offline when necessary, synchronizing data with the centralized hub once a connection is restored. Such capabilities ensure data consistency and reliability, even in remote farming environments.

The interface incorporates data visualization techniques to improve user comprehension and operational awareness. By converting latitude and longitude data into real-time interactive maps, the system simplifies the monitoring of machinery locations and statuses. These visualizations align with the principles outlined by Tisljaric, [18] which emphasize the importance of turning geographical data into interpretable visual formats. Farm staff can view segmented zones, track machinery movements, and identify trends or anomalies at a glance, enhancing situational awareness and decision-making.

Finally, the system use customizable dashboards to provide users with tailored insights. Inspired by the studies of Guevara *et al.,* [21] and Barthélemy *et al.,* [23] which explore the use of dashboards in traffic and flight tracking, this feature allows farm managers to prioritize specific data, such as activity timelines or machinery categories. By personalizing views, staff can focus on the most relevant information, improving productivity and resource management.

Overall, the interface design integrates visualization techniques, centralized data management, and real-time location tracking to create an intuitive and efficient tool for farm operations. By addressing traditional inefficiencies and aligning with best practices in data management and visualization, the system empowers farm staff to make informed decisions, optimize machinery usage, and enhance overall productivity.

2.7 User Feedback and Evaluation

To evaluate the usability and effectiveness of the Real-Time Machine Tracking and Monitoring System, a structured survey was administered to 15 farm staff members who participated in testing the system. The survey aimed to gather feedback on several key aspects, such as ease of use, visual design, the clarity of map markers and notification alerts, and the overall efficiency of the system in assisting users with machine management. The results were quantified and analysed, and figures have been included to visually represent the findings.

As shown in Figure 4, it presents the familiarity of users with digital tools and technology. The survey showed that 60% of respondents were very familiar with digital tools, while 20% reported limited familiarity and other 20% reported they are not familiar. This highlights the importance of ensuring the system is accessible to users with varying levels of technological proficiency. Given that the system was designed to cater to users with limited technical expertise, the high percentage of users who found it easy to use was encouraging.

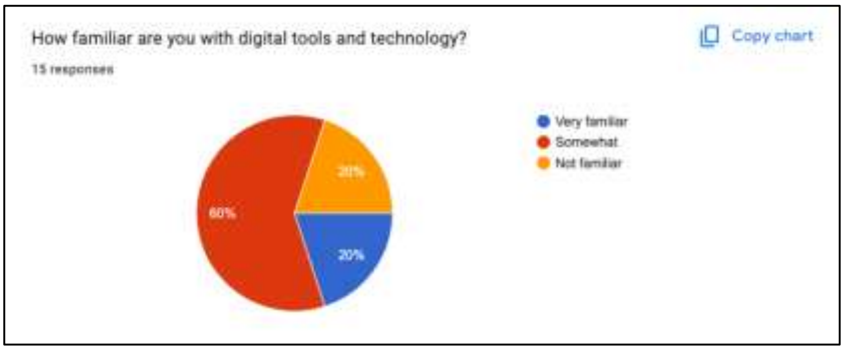

Fig. 4. Familiarity with digital tools

As shown in Figure 5, 86.7% of the users found the system easy to use, suggesting that the interface was intuitive and accessible. The survey also inquired about the clarity of the map markers and notification alerts as shown in Figure 6. All participants reported that the map markers and alerts were clear and easy to understand, indicating that the system's key features effectively communicated critical information to the users, even those with minimal digital experience.

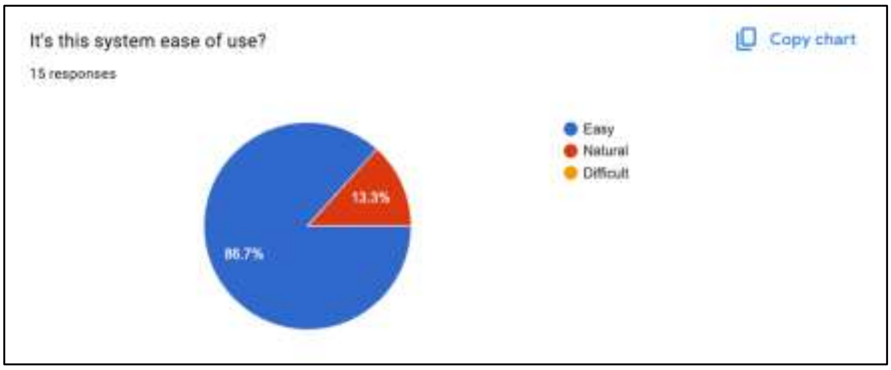

Fig. 5. Ease of use

Fig. 6. Clarity of map markers and notification alerts

In terms of system performance, Figure 7 illustrates the time it took for users to locate machines. While 78.6% of users were able to locate machines quickly, other felt neutral about the speed. This feedback suggests that the system is generally effective in helping users quickly find machines, though further optimization could be considered for those who felt neutral.

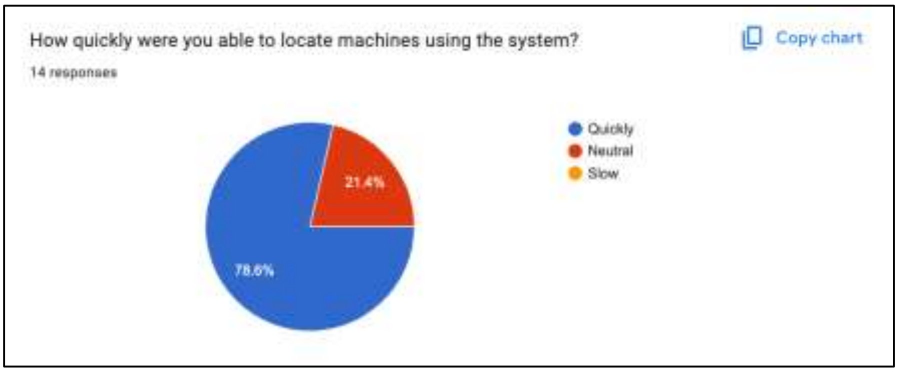

Fig. 7. Speed of locating machines

When asked about the visual design of the system, Figure 8 shows that 60% of the respondents rated the design as "excellent," while the other rated it as "good." This indicates that the visual elements, including the colour scheme, layout, and icons, were well-received by the users. The feedback emphasizes the importance of design in ensuring user engagement and comprehension.

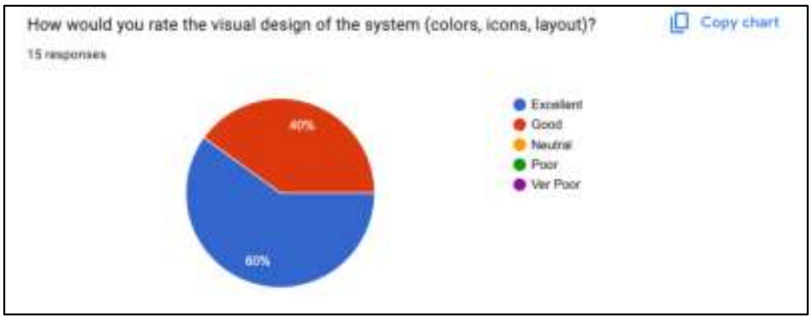

Fig. 8. Visual design rating

Regarding the information provided for decision-making, Figure 9 shows that 66.7% of users felt the system provided all the necessary information to make informed decisions about machine management, while the remaining 33.3% felt that the system provided most of the information. This suggests that while the system is largely effective, there is still room for improvement in ensuring that all critical information is easily accessible for decision-making.

Fig. 9. Information for decision-making

Lastly, Figure 10 illustrates the overall satisfaction of users, with 100% of respondents expressing satisfaction with the system. This high level of satisfaction indicates that the system is meeting the expectations of the farm staff, with positive feedback about its usability and functionality.

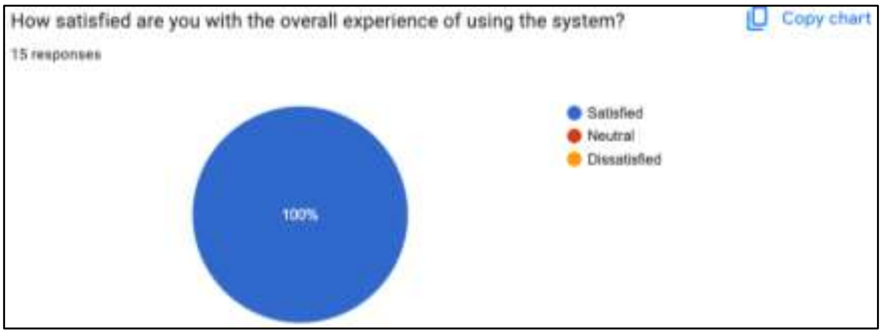

Fig. 10. Overall satisfaction

The insights gained from this survey have been instrumental in refining the system's design and features. The data highlights areas of strength, such as ease of use, clarity of communication, and overall satisfaction, as well as areas for potential improvement, such as further optimizing machine location speed and providing more comprehensive decision-making data. The feedback will continue to guide future system updates to enhance its effectiveness and ensure it remains a valuable tool for farm management.

3. Results

The results of this study demonstrate the successful implementation of the Real-Time Machine Tracking and Monitoring System designed for palm oil farms. The system integrates IoT technology, edge computing, and a user-friendly interface to provide real-time data visualization and operational insights. Key features include a dynamic dashboard for monitoring machine locations and statuses, a detailed section for analyzing individual machinery, and notification alerts for prolonged activity to prevent overuse. The system also incorporates a farm visualization component that segments the farm into zones for better resource allocation. Additionally, tailored lists, such as the truck filter feature, allow for efficient category-specific management. These results highlight the system's capability to optimize farm operations by automating machine tracking, reducing manual effort, and supporting informed decision-making processes. The following figures illustrate these features in detail.

The dashboard as shown in Figure 11 is the main interface of the Real-Time Machine Tracking and Monitoring System, providing a comprehensive overview of all monitored machines in palm oil farms. The dashboard features a map on the left side that displays the real-time locations of all machines, offering an interactive way for users to track their movements. On the right side of the map, there is a calendar and a list of active machines. The list below the calendar dynamically shows all active machines, with real-time updates based on their statuses, such as whether they are out of the office location (active) or within the office location (inactive). At the top of the dashboard, there is a search bar for quick access, a notification icon, a favorite icon, and the user’s name and profile image.

Additionally, the notification system as shown in Figure 12 is integrated into the dashboard to alert users when machines have been active for more than 7 hours, meaning they have been out of the office location for an extended period. Once this threshold is reached, a pop-up notification appears every 30 minutes to inform the user, ensuring that machines are regularly monitored for overuse and timely intervention.

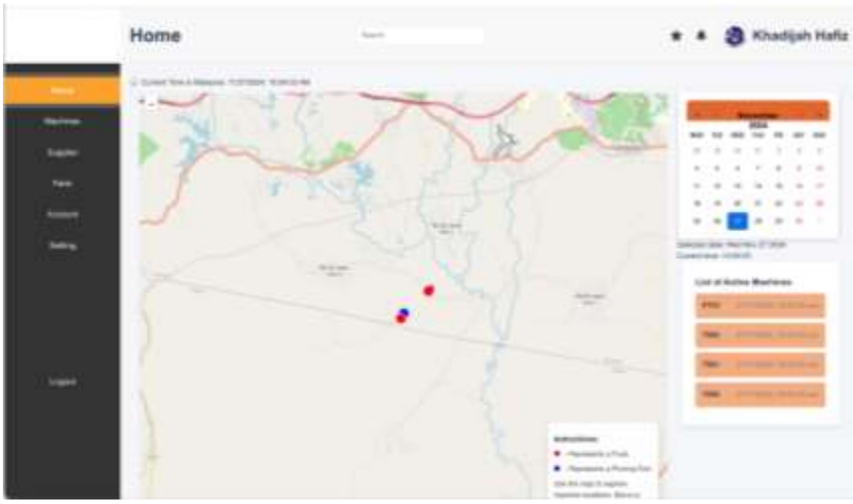

Fig. 11. Dashboard with real-time machine locations, calendar and active machines list

Fig. 12. Pop-up notification for machines active beyond 7 hours

The Machines' Part as shown in Figure 13 allows users to select different categories of machinery, such as trucks or pruning tools, for targeted management. This interactive feature enables users to refine their focus based on the type of equipment they wish to monitor. Upon selecting a category, such as "Truck," the system displays a List of Trucks as shown in Figure 14. This list provides essential information about each truck, including IDs, names, supplier IDs, statuses, and purchase date, ensuring streamlined logistics and effective resource allocation. This seamless navigation between machine categories and detailed lists enhances user experience and operational efficiency by providing tailored data views for specific equipment types.

Fig. 13. Machines’ part

Fig. 14. List of truck

Then, by clicking on the ID of a specific truck, users are redirected to a detailed page showcasing more comprehensive information about the selected machine. This detail page as shown in Figure 15 presents essential data, including the machine's supplier ID and name, operational date, latitude and longitude coordinates, status and a real-time map on the right side displaying the truck's current location. The map provides a dynamic visual representation of the machine’s location, enabling users to track its real-time movement within the farm. This feature ensures that users can access both high-level and granular information, enhancing decision-making and management of farm machinery.

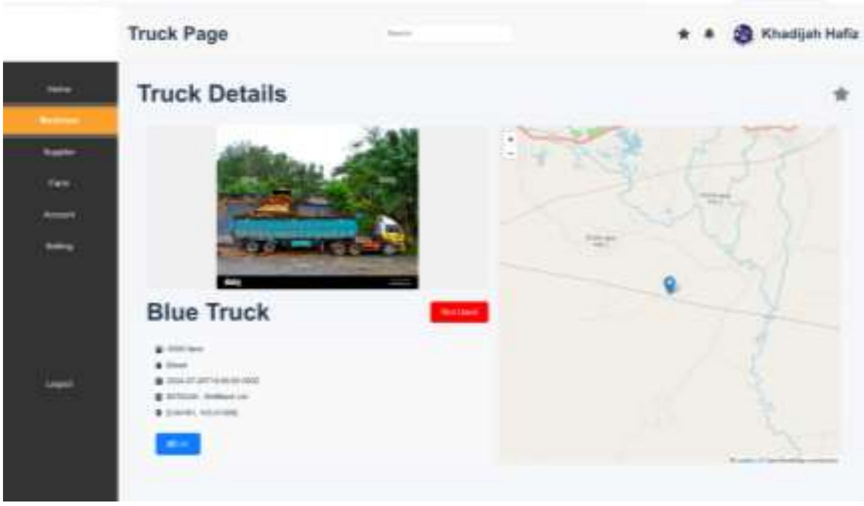

Fig. 15. Truck details

Figure 16 illustrates the Farm Part, which visually represents the entire palm oil farm, divided into various operational zones. This component is essential for farm managers and staff to monitor machine activity across different areas of the farm. The map displays the machine locations in real time, with each machine's status and route highlighted as they move between different zones, such as the office zone, harvesting zone, or other areas within the farm. This feature enables users to quickly assess the distribution of machines across the farm and make informed decisions about resource allocation and task assignment.

On the right side of the map, the system shows a detailed layout of the farm's zones, highlighting key areas where machines are assigned specific tasks. For example, it may display zones like "Zone 1: Office" and "Zone 2: Harvesting," allowing staff to identify which machines are operating in which zones at any given moment. The integration of machine locations with the farm's zone structure improves operational efficiency, as it provides clear visibility into which areas are being covered and whether any zones are under-served or over-served.

Additionally, real-time updates are reflected in the system, ensuring that the farm manager can track machine movements and make timely decisions. This helps avoid bottlenecks, improves task management, and ensures that no zone is left unattended. The visual representation of the farm's zones also allows staff to monitor how effectively the machines are being utilized and whether reallocation or maintenance is necessary.

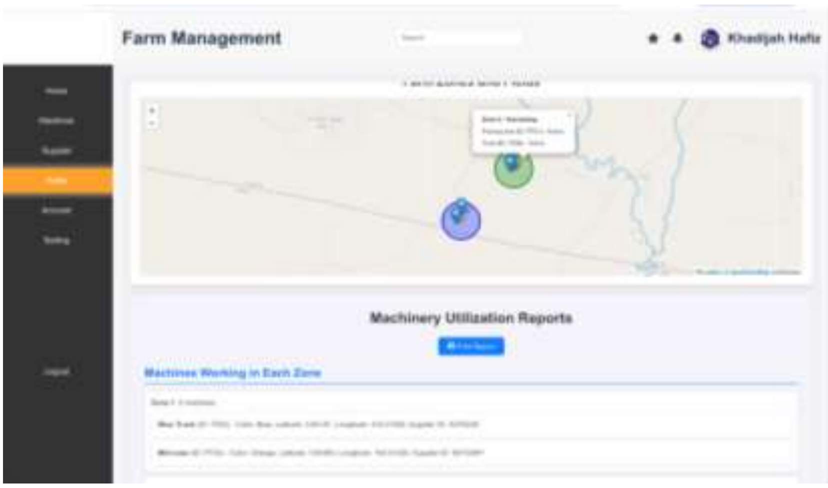

Fig. 16. Farm part

3.1 Scalability and Adaptability

The Real-Time Machine Tracking and Monitoring System is designed to function in regions with limited Internet connectivity, showing foresight in accommodating diverse operational environments. The use of IoT technology and edge computing ensures its applicability across various farm fields, addressing common challenges such as remote locations and connectivity issues. Meanwhile, the user-friendly interface and intuitive data visualization further enhance its usability across different user groups, including non-technical farm workers. In regards system scalability, our centralized server approach allows for efficient data aggregation and processing, supporting the potential expansion to monitor more machines or integrate additional sensors. However, the scalability could depend on the fam office’s server capacity to handle a larger number of data streams or geographically dispersed machinery. Overall, the real-time system's adaptability makes it well-suited for deployment in various farming scenarios, while its scalability is promising, contingent on further technical enhancements.

4. Conclusion

In conclusion, this study successfully developed a real-time machine tracking and monitoring system specifically designed for palm oil farms, effectively addressing the primary research objective of enhancing operational efficiency through real-time data collection and analysis, even in areas with limited Internet access. By integrating IoT sensors, edge computing, and a user-friendly interface, the system provides real-time tracking of machine locations and statuses, eliminating the errors and inefficiencies associated with manual tracking methods. The results demonstrate that the system significantly reduces manual monitoring efforts, improves the accessibility of machine data, and supports more informed decision-making processes. Key features such as real-time notifications for extended machine inactivity and the visualization of farm zones and machine movements on interactive maps directly address the challenges of managing operations on large-scale palm oil farms. The use of IoT-enabled devices, combined with edge computing, ensures accurate and timely updates even in areas with limited internet connectivity. Nonetheless, future studies could focus on integrating predictive maintenance features and advanced data analytics to optimize farm operations. These enhancements could support more farming practices, ensuring that the real-time information system remains a valuable tool for improving efficiency and productivity in palm oil plantations.

Acknowledgement
This work is supported by the Geran Putra (GP-IPS/2023/9747400), funded by Universiti Putra Malaysia.

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