

Development of a Smart Monitoring System for Palm Oil Processing Using Internet of Things Technology

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Abstract

Palm oil mills operate with limited real-time visibility of their own processes, so that deviations in temperature, level, throughput, and product quality are typically detected through periodic laboratory analysis rather than as they occur. This paper develops a system architecture for Internet of Things based monitoring of palm oil processing and specifies the design requirements that distinguish workable installations from those that fail after commissioning. The study followed a design research approach in which functional requirements were elicited from published mill-level monitoring implementations indexed in Scopus and SINTA, an architecture was synthesised, and evaluation criteria were derived and applied analytically to the proposed design. The resulting architecture comprises four tiers: instrumentation at the unit operation, edge acquisition and local control, a communication and integration layer, and an analytics and visualisation layer. The review of existing implementations indicates that sensing at the continuous settling tank, sterilizer, boiler, and effluent pond is technically straightforward with low-cost microcontroller hardware, but that sensor linearity outside a narrow measurement range, the absence of calibration procedures, and the lack of integration with existing supervisory control systems repeatedly limit operational value. The paper argues that the binding design constraint in this application is not connectivity but measurement traceability, and proposes that any deployment specify calibration intervals, acceptable measurement ranges, and a defined action for each monitored variable before hardware is selected.

Keywords: Internet of Things; palm oil mill; smart monitoring

Introduction

A palm oil mill is a continuous process plant operated with instrumentation that is sparse by the standards of comparable process industries. Sterilizer pressure and boiler drum level are typically monitored because safety requires it, while the variables that govern product quality and oil recovery, including continuous settling tank temperature, dilution water ratio, press cake condition, and effluent characteristics, are assessed through periodic manual sampling. The interval between sampling points defines the mill's reaction time, and it is commonly measured in hours.

The consequence is a specific operational pattern. A process deviation persists until the next laboratory result reveals it, by which time a substantial tonnage has already been processed under the deviant condition. Because oil losses are diffuse and appear across several streams, the financial consequence is rarely traced back to the originating deviation, and the mill therefore has weak feedback on the value of faster detection.

Internet of Things technology addresses precisely this latency. Low-cost microcontrollers, industrial sensors, and wireless communication now permit continuous acquisition at points where instrumentation was previously uneconomic. Fakhruddin and Priyanto (2024)

implemented optical sensing for real-time water content monitoring in palm oil processing and demonstrated both the feasibility of the approach and one of its central limitations, reporting that measurement remained usable within a narrow moisture range while sensor response became markedly non-linear beyond it. Rizal and Dachyar (2021) approached the question from the selection side, evaluating candidate technologies for palm oil mill maintenance applications and concluding that the choice is governed by compatibility and fault tolerance criteria rather than by sensing capability alone.

The wider oil palm digitalisation literature has developed largely at the plantation rather than the mill scale. Akhtar et al. (2023) reviewed remote sensing and artificial intelligence applications in plantation management, and Abubakar and Ishak (2024) examined the intersection of digitalisation and sustainability across the sector, concluding that the transformative potential of these technologies depends on integration with operational systems rather than on their standalone capability. Comparable synthesis for the processing plant is thinner, and published mill implementations tend to report individual sensing demonstrations without specifying the architecture into which they fit.

This paper addresses that gap. Its objective is to develop a system architecture for Internet of Things monitoring of palm oil processing and to specify the design requirements that determine whether an installation remains useful after commissioning. The contribution is architectural and prescriptive rather than demonstrative: rather than reporting another sensing prototype, the paper identifies the failure modes evident in the published implementations and derives design requirements that address them.

Method

The study followed a design research approach comprising requirement elicitation, architecture synthesis, and analytical evaluation. This approach is appropriate where the objective is to produce a defensible design specification rather than to test a hypothesis.

Requirements were elicited from published implementations and technology assessments retrieved from Scopus and SINTA-accredited journals for the period 2015 to 2025. Search strings combined technology terms (“Internet of Things”, “real-time monitoring”, “wireless sensor”, “SCADA”, “predictive maintenance”) with domain terms (“palm oil mill”, “palm oil processing”, “agro-industry”). Each retained record was examined for the variable monitored, the sensing hardware employed, the communication method, the reported performance, and any limitation stated by the authors. Limitations were recorded verbatim in the extraction sheet, since these proved to be the most informative content for design purposes.

Architecture synthesis grouped the elicited requirements by the system function they addressed and assigned each to a tier. Tiers were separated where the engineering discipline, failure mode, and maintenance regime differed materially, on the reasoning that a boundary drawn at these points corresponds to a real division of responsibility in an operating plant.

Analytical evaluation assessed the proposed architecture against four criteria derived from the elicited limitations: measurement traceability, integration with existing control infrastructure, maintainability under mill conditions, and defined actionability of each monitored variable. Evaluation was conducted by walking each criterion through each tier and identifying the design provision that satisfies it. As this is a design study based on published evidence, no physical prototype was constructed and no field performance data are reported; the architecture is presented as a specification for subsequent implementation and testing.

Result and Discussion

Proposed four-tier architecture

The synthesised architecture separates the monitoring system into four tiers. The instrumentation tier comprises sensors installed at the unit operation, selected for the process conditions they must survive. The edge tier comprises local acquisition, signal conditioning, and any control action that must execute without network dependence. The integration tier carries data to the plant network and reconciles it with existing supervisory systems. The analytics tier converts the resulting time series into diagnosis, alarm, and reporting.

Table 1. Tiers of the proposed monitoring architecture and their design requirements

No	Tier	Function and typical monitored variables	Governing design requirement
1.	Instrumentation	Sterilizer pressure, settling tank temperature, boiler parameters, effluent pond level	Calibrated measurement within a declared valid range
2.	Edge acquisition	Local logging, signal conditioning, fail-safe local control	Continued operation during network loss
3.	Integration	Transport to plant network, reconciliation with supervisory systems	Compatibility with installed control infrastructure
4.	Analytics	Trending, alarm generation, maintenance prediction, reporting	A defined action attached to every alarm

The tier boundaries correspond to real divisions of responsibility. Instrumentation is maintained by the mill's instrument technicians and fails through fouling, drift, and mechanical damage. Edge devices are maintained by electrical staff and fail through power quality and environmental exposure. Integration is an information technology function and fails through protocol incompatibility. Analytics is a process engineering function and fails through the generation of alarms that nobody acts upon. Designing across these boundaries without acknowledging them is a common source of systems that operate briefly and are then abandoned.

Measurement traceability as the binding constraint

The most consistent finding from the reviewed implementations is that connectivity is not the difficult part. Microcontroller platforms, temperature and level sensors, and wireless transport are inexpensive and well documented, and demonstrations of these components in mill settings are readily achieved. What limits operational value is whether the resulting number can be trusted.

Fakhrudin and Priyanto (2024) illustrate this precisely. Their optical approach to water content measurement functioned within a limited moisture range, with sensor response becoming non-linear beyond it, and required correction of that non-linearity before the readings approximated actual water content. This is not a defect peculiar to that study; it is the normal condition of low-cost sensing applied to an industrial medium, and it generates a specific design obligation. Every monitored variable requires a declared valid measurement range, a stated accuracy within that range, a calibration procedure, and a calibration interval. Without these, a continuously displayed value conveys false confidence, which is operationally worse than an acknowledged gap in knowledge.

Rizal and Dachyar (2021) reinforce the point from the technology selection perspective, finding that compatibility and fault tolerance dominate the selection criteria for mill applications. A monitoring system that cannot be reconciled with an existing supervisory installation produces a second, competing version of plant state, and operators respond rationally by trusting the system they have used for years.

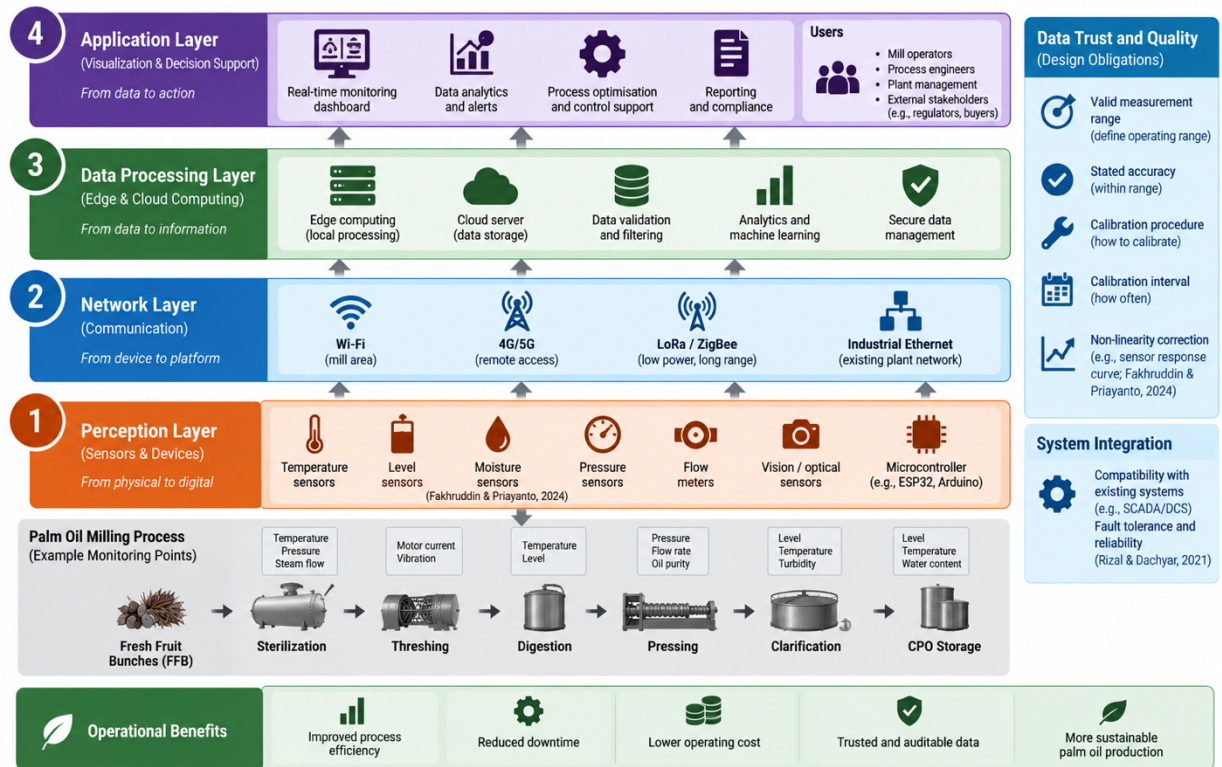


Figure 1. Four-tier architecture for Internet of Things monitoring of palm oil processing

Extending monitoring to quality and reception

The architecture accommodates quality monitoring at the reception station, which is where the largest information gap in most mills lies. Fruit grading determines the quality ceiling of everything downstream, yet it is performed visually and inconsistently. Automated grading is now well developed: Suharjito et al. (2021) demonstrated ripeness classification on mobile devices using lightweight convolutional networks, Suharjito et al. (2023) published annotated datasets collected directly from mill grading stations, and Rosbi et al. (2024) showed that segmentation combined with textural features achieves useful grading performance without the large image datasets that deep learning approaches require. Savaş (2024) demonstrated related ensemble methods in a palm disease context.

Two integration requirements follow. First, a grading result is only useful if it is linked to the batch identity that carries through sterilization and pressing, which means the monitoring system must maintain a batch record rather than only a set of independent time series. Second, the grading model must be revalidated against local conditions, since lighting, camera geometry, and cultivar affect classification performance, and a model transferred without revalidation will degrade silently.

The limitations of the present study should be stated. The architecture is derived analytically from published implementations and has not been constructed or tested in an operating mill, so the cost, commissioning effort, and maintenance burden estimates that a mill would require before committing capital are not established here. In addition, the reviewed implementations are dominated by single-variable demonstrations, which means the integration tier requirements rest on general process automation practice rather than on mill-specific evidence.

Conclusion

This paper set out to develop a system architecture for Internet of Things monitoring of palm oil processing and to identify the requirements that determine post-commissioning usefulness. The proposed four-tier architecture separates instrumentation, edge acquisition, integration, and analytics along boundaries that correspond to distinct failure modes and maintenance responsibilities within an operating mill.

The principal finding is that the binding constraint in this application is measurement traceability rather than connectivity. Published implementations demonstrate that sensing and transport are readily achieved, while sensor linearity limits, absent calibration regimes, and weak integration with existing supervisory systems repeatedly erode operational value. The design implication is that a deployment should declare the valid measurement range, accuracy, calibration procedure, and calibration interval for every variable, and should attach a defined operator action to every alarm, before any hardware is selected. Subsequent work should implement and instrument the proposed architecture in an operating mill and report commissioning effort, measurement drift over a full season, and the operational decisions actually changed by the additional data.

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