



The Smart Integrated System for Milk Collection and Distribution

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Abstract—Milk collection and distribution involve supplier identification, quantity measurement, quality assessment, payment, storage, inventory control, and dispensing. When these activities are managed through disconnected or manual processes, traceability and timely access to information become difficult. This paper presents a Smart Integrated System for Milk Collection and Distribution that combines Internet of Things (IoT) sensing, Radio-Frequency Identification (RFID), an ESP32 (Espressif Systems 32-bit microcontroller) based controller, server-side processing, database management, web-based administration, payment records, inventory monitoring, and controlled milk distribution. At the collection point, an RFID identifier is associated with a farmer transaction, while a load-cell interface and selected sensors provide quantity, pH (potential of hydrogen), and temperature observations. The controller transmits each transaction to application services, where validation and persistent storage are performed. An administrative dashboard provides access to farmer records, collection history, quality observations, payments, storage status, and distribution records. The distribution module supports consumer transactions and can be extended with flow sensing for automated dispensing. The architecture provides a unified digital trail from collection to distribution. Because verified field measurements were not available, this paper does not report fabricated accuracy or performance values; a field study is proposed to evaluate measurement error, communication latency, reliability, security, and scalability.

Index Terms—Internet of Things, smart dairy management, milk collection, RFID, ESP32, milk quality monitoring, cloud computing, inventory management.

I. INTRODUCTION

Milk is a perishable agricultural product whose value chain depends on timely collection, quality assessment, appropriate storage, and controlled distribution. Dairy collection centers must maintain information about suppliers, quantities received, quality observations, payments, storage capacity, and downstream transactions. In small and medium operations, these activities are often distributed among paper registers, weighing equipment, laboratory instruments, spreadsheets, and separate payment records. Such fragmentation makes individual transactions difficult to trace and increases the effort needed for reconciliation and reporting.

The Internet of Things (IoT) provides a technological basis for connecting physical objects, sensors, identification devices, communication networks, and software services. The IoT literature identifies identification, sensing, communication, and distributed processing as the important elements of connected systems [1], [2]. Radio-Frequency Identification

(RFID) and sensor technologies are therefore suitable for linking physical dairy events with digital records.

This work proposes a unified platform that connects farmer identification, milk collection, quality observations, payment records, storage and inventory, and distribution. The system separates physical sensing from application services so that individual hardware components can be upgraded without redesigning the complete platform. The contribution of this paper is an end-to-end architecture for traceable dairy transactions rather than an isolated sensor-monitoring device. The main contributions are: (1) a layered architecture that links collection, payment, storage, and distribution through common transaction identifiers; (2) a hardware design based on an ESP32 (Espressif Systems 32-bit microcontroller) controller with RFID, load-cell, pH, temperature, and flow sensing; (3) a web-based software design with role-based access; and (4) an evaluation plan that avoids unsupported performance claims.

II. RELATED WORK

Atzori, Iera, and Morabito describe the IoT as a convergence of identification, sensor and actuator networks, communication technologies, and distributed intelligence [2]. Gubbi et al. discuss a cloud-centric IoT model in which connected objects generate data that must be stored, processed, and presented through services [1]. These principles motivate the proposed architecture, where collection-point devices produce observations and application services convert them into persistent dairy records.

RFID is useful when an entity must be identified repeatedly without manual entry [4]. In this system, an RFID identifier is associated with a farmer profile. The identifier is treated only as a reference to a record; authorization remains a software responsibility. Industrial IoT research also emphasizes modular communication architectures and the integration of distributed devices with higher-level services [3]. The proposed dairy platform applies this layered principle by separating sensing, communication, application logic, persistence, and user interfaces.

Lightweight messaging protocols such as Message Queuing Telemetry Transport (MQTT) are widely used for device telemetry [5], and the current design uses HTTP (Hypertext Transfer Protocol) based Representational State Transfer (REST) calls while keeping MQTT as an extension. The project focuses on the integration of collection, quality, payment, inventory, storage, and distribution into one traceable workflow, which is the gap addressed in this paper.

III. PROBLEM STATEMENT AND OBJECTIVES

The problem is the absence of a unified digital workflow in which farmer identity, milk quantity, quality observations, payment, inventory, and distribution events can be linked and retrieved from a common system. Manual processes may require repeated data entry and make timely reporting difficult.

The objectives of the work are to: (1) identify farmers electronically; (2) capture milk quantity and selected quality observations; (3) transfer device observations to a server; (4) maintain structured records; (5) provide role-based monitoring; (6) maintain payment histories; (7) track storage and inventory movement; and (8) support controlled milk distribution and transaction recording.

IV. PROPOSED SYSTEM

A. Overview

The system is organized into physical collection, IoT control and communication, application services, data management, and distribution layers. The collection layer contains the RFID and sensing components. An ESP32-class controller interfaces with the sensors and communicates with the application services. The application layer performs validation, business rules, authentication, authorization, and transaction processing. The database stores persistent records, and a web client presents them to administrators, farmers, and consumers.

B. Collection Transaction

A collection transaction begins when a farmer presents an RFID identifier. The system retrieves the farmer profile and opens a transaction. Milk quantity is acquired from the weighing subsystem. If available and calibrated, pH and temperature values are also acquired. The controller packages the observations with a timestamp and a transaction reference and sends them to the server. The server validates and stores the transaction and associates the payment information with it.

C. Distribution Transaction

A distribution transaction starts with a consumer request and quantity selection. After payment verification, the dispensing mechanism can be enabled. A flow sensor can provide an observation of the dispensed quantity. The transaction is then completed and the inventory is updated. This modular architecture can later support notifications, mobile applications, MQTT telemetry, analytics, and automated dispensing.

V. SYSTEM ARCHITECTURE AND DATA FLOW

Fig. 1 shows the layered architecture of the proposed system. The physical layer holds the sensing and actuation devices at the collection and distribution points. The ESP32 controller in the IoT control layer gathers the observations and sends them through the communication layer to the application layer, which stores validated records in the data layer. The presentation layer gives each user role a suitable view of the same records.

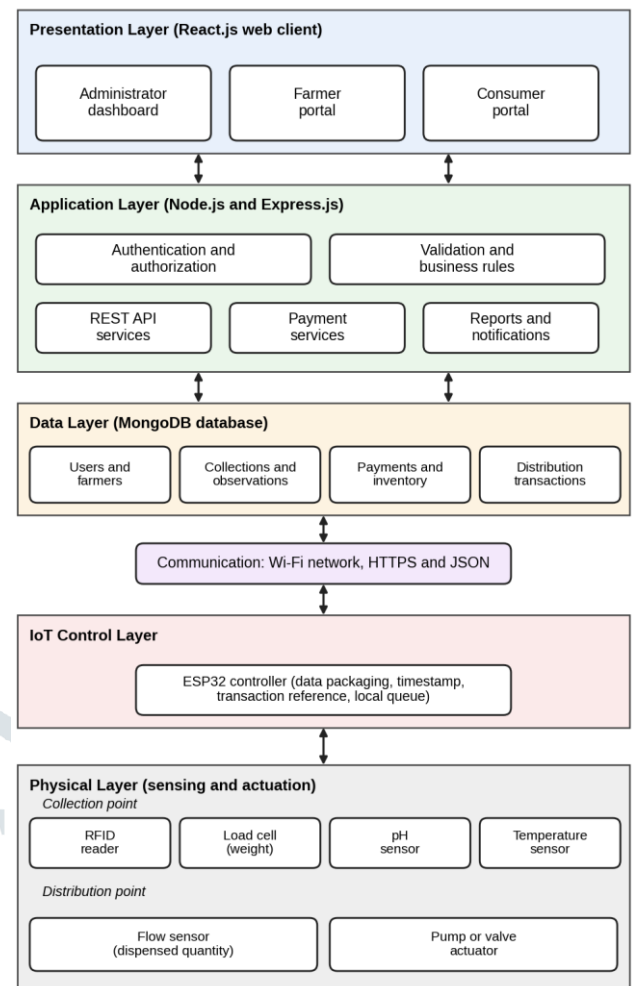


Fig. 1. Layered architecture of the Smart Integrated System for Milk Collection and Distribution.

The two principal data flows are shown in Fig. 2. The collection data flow is: farmer RFID identification, sensor acquisition, ESP32 controller, network and Application Programming Interface (API), server validation, database, and finally dashboard and payment services. The distribution flow is: consumer, quantity selection, payment verification, dispensing control, flow observation, transaction completion, inventory update, and receipt or history.

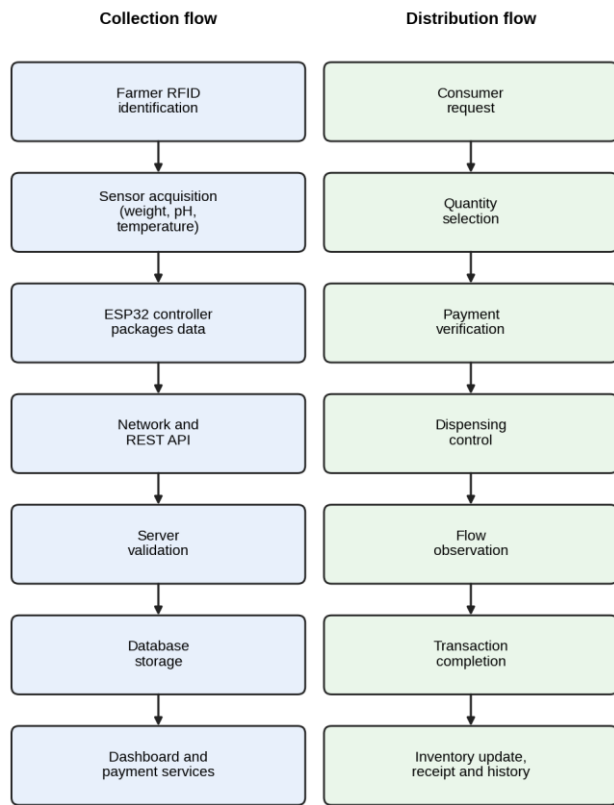


Fig. 2. Data flow for the collection and distribution transactions.

Core database entities include User, Farmer, Consumer, Milk Collection, Sensor Observation, Payment, Storage Unit, Inventory Transaction, Notification, and Distribution Transaction. A Milk Collection record is associated with a farmer and can reference sensor observations and payment information. Inventory is preferably maintained through transaction history so that stock movement can be audited. Server-side validation is required even when the client performs validation.

VI. HARDWARE IMPLEMENTATION

An ESP32 development board serves as the local controller. An RFID reader provides farmer identification. A load cell with suitable signal conditioning provides a weight measurement. A pH sensor and a temperature sensor provide selected quality observations. The exact sensor models and calibration procedures should be documented according to the hardware actually used. Table I summarizes the hardware components and their roles.

TABLE I
HARDWARE COMPONENTS AND THEIR ROLES

Component	Role in the system	Remark
ESP32 development board	Local controller and network gateway	Packages observations with timestamp and transaction reference
RFID reader and tags	Electronic farmer identification	Identifier is a reference to a record, not proof of identity
Load cell with signal conditioning	Milk weight measurement	Calibrated with known masses
pH sensor	Selected quality observation	Requires calibration against a reference
Temperature sensor	Selected quality observation	Compared with a reference instrument
Flow sensor	Dispensed quantity observation	Used in the distribution module
Actuator (pump or valve)	Controls dispensing	Needs driver circuit and electrical isolation

For distribution, a flow sensor provides a measurement of the dispensed liquid and an actuator controls dispensing. Appropriate driver circuitry and electrical isolation are required when the controller operates higher-power loads.

Calibration is essential. A pH or temperature value should not be treated as laboratory-grade without calibration and comparison against an appropriate reference instrument. Similarly, the weighing subsystem should be calibrated with known masses. The system therefore records sensor values as operational observations unless they are validated by a defined quality procedure.

VII. SOFTWARE IMPLEMENTATION

The web application uses React.js for the user interface, Node.js with Express.js for server-side APIs, and MongoDB for persistent storage. REST APIs connect the web client and the server, and JavaScript Object Notation (JSON) is used as the data exchange format. Role-based access provides separate administrator, farmer, and consumer functions.

Authentication uses secure password hashing and an authenticated session or token mechanism. Authorization middleware protects administrative endpoints. Database credentials, token secrets, and payment credentials are kept outside the source code. The dashboard displays collection totals, inventory, storage status, payment status, quality observations, and distribution activity. Historical records can be filtered by farmer, date, status, or collection unit.

The server-side services are separated by responsibility, as listed in Table II. This separation allows each service group to be tested and modified independently.

TABLE II
APPLICATION PROGRAMMING INTERFACE SERVICE GROUPS

Service group	Responsibility
Authentication	Login, token or session issue, role check
Farmer management	Create, read, update and deactivate farmer records and RFID mapping
Collection	Receive device transactions, validate and store them
Quality	Store and query pH and temperature observations, raise alerts
Payment	Record payment amount, reference, status and date
Inventory and storage	Record stock movement and report storage level
Distribution	Handle consumer requests, payment check and dispensing status
Reporting	Filtered summaries by farmer, date, status or collection unit

VIII. DATABASE DESIGN

Persistent data is held in MongoDB collections that correspond to the entities named in Section V. Table III lists the entities with representative content. The fields shown are representative and can be extended according to the requirements of a particular dairy center.

TABLE III
DATABASE ENTITIES AND REPRESENTATIVE CONTENT

Entity	Representative content
User	Login identity, role (administrator, farmer, consumer), hashed password
Farmer	Profile, contact details, RFID identifier, collection unit
Consumer	Profile and contact details for distribution transactions
Milk Collection	Farmer reference, quantity, timestamp, transaction reference, status

Entity	Representative content
Sensor Observation	pH, temperature and weight values linked to a collection event
Payment	Amount, transaction reference, status, date
Storage Unit	Capacity, current level, location
Inventory Transaction	Stock movement into or out of a storage unit, with reference
Distribution Transaction	Consumer request, quantity, payment state, dispensing status
Notification	Configurable alert, recipient, status

Each record carries a unique transaction identifier. Related records, such as a collection, its sensor observations, its payment, and the resulting inventory movement, share this identifier so that an administrator can trace an event across modules. Inventory balances are derived from the sequence of inventory transactions instead of being edited directly, which keeps stock movement auditable.

IX. FUNCTIONAL MODULES

Farmer Management maintains farmer profiles and RFID identifiers. Milk Collection records farmer identity, quantity, timestamp, and available quality parameters. Quality Monitoring associates pH and temperature observations with collection events and can raise configurable alerts. Payment Management maintains the amount, transaction reference, status, and date. Storage and Inventory tracks milk entering and leaving storage. Milk Distribution records consumer requests, payment state, dispensing status, and quantity. Notifications and Reports provide configurable alerts and summaries.

The modules are connected through transaction identifiers so that an administrator can trace a collection event and its related payment or inventory movement. This reduces the need to reconcile separate manual records.

X. OPERATIONAL SCENARIO AND USER ROLES

The operation of the system can be described through one working day at a collection center. When a farmer arrives, the RFID tag is read and the farmer profile is displayed to the operator. The milk is weighed, and where the sensors are installed, pH and temperature observations are captured. The controller then sends one packaged transaction to the server. The server rejects incomplete or out-of-range data, stores valid data, and creates the linked payment entry and the inventory movement into the selected storage unit. The farmer can later view the same record on the farmer portal, and the administrator can see it on the dashboard without any re-entry.

In the evening, a consumer can request milk at the distribution point. The server checks the payment status, enables dispensing for the selected quantity, records the flow observation when a flow sensor is fitted, and reduces the stock in the storage unit. The access given to each role is summarized in Table IV.

TABLE IV
USER ROLES AND FUNCTIONS

User role	Functions available
Administrator	Manage farmers and RFID mapping, view collections, quality observations, payments, storage, inventory and distribution records, generate reports
Farmer	View own collection history, quality observations, payment status and notifications
Consumer	Request milk, select quantity, complete payment, view transaction history and receipts

Because every step is stored against the same transaction identifier, the records of a day can be reconciled by filtering on

date, farmer, status, or collection unit. If the network is unavailable during a collection, the local queue holds the transaction on the controller and the record is synchronized after reconnection.

XI. SECURITY AND RELIABILITY

The system handles user and transaction information, so security must be considered throughout the architecture. Passwords should never be stored in plain text. Role-based authorization should be enforced on the server. API inputs should be validated for type, range, length, and required fields.

IoT devices introduce additional security considerations. Device credentials should not be exposed in public repositories. Communication should use encrypted transport where supported. Unexpected device values should be rejected or flagged. For intermittent connectivity, a local queue can buffer transactions and synchronize them after reconnection, and unique transaction identifiers help prevent duplicate records.

Reliability also depends on power stability, sensor calibration, network availability, and database backup procedures. A production deployment should include device health monitoring, backup, and recovery mechanisms.

XII. RESULTS AND EVALUATION

The integrated design creates a digital trail from collection to distribution and provides a common operational view. RFID can simplify repeated farmer identification, while sensor integration associates observations with transactions. The dashboard consolidates collection, payment, inventory, and distribution information.

No verified experimental dataset was available for this manuscript. Therefore, numerical accuracy, percentage improvement, cost savings, response-time reduction, and user-satisfaction claims are not reported. A rigorous evaluation should follow the plan in Table V.

TABLE V
PROPOSED EVALUATION PLAN

Evaluation aspect	Proposed measurement method
Weighing accuracy	Load-cell error against reference masses
pH accuracy	Deviation against a calibrated reference meter
Temperature accuracy	Deviation against a calibrated thermometer
Transmission latency	End-to-end time from sensing to stored record
API response time	Server response for each service group under load
Transaction success rate	Stored transactions divided by attempted transactions
Inventory consistency	Ledger balance compared with physical stock
Network recovery	Records synchronized after a connection interruption
System availability	Uptime over the observation period

Each experiment should document its test setup, number of trials, reference method, statistical summary, and limitations. This will allow reproducible quantitative results to be reported in place of unsupported estimates.

XIII. ADVANTAGES AND APPLICATIONS

The system provides centralized records, electronic identification, transaction traceability, digital payment history, inventory visibility, and a common administrative interface. It can be adapted for cooperative collection centers, dairy farms, milk booths, and controlled milk vending facilities. The modular design allows gradual adoption, beginning with

digital collection records and later adding automated dispensing and real-time telemetry.

XIV. LIMITATIONS

The system depends on correct sensor installation and calibration, network connectivity, power availability, and reliable database services. RFID is an operational identifier and should not be treated as complete identity verification. Sensor drift can affect measurements. External payment and notification services introduce dependencies. Production deployment requires stronger security controls, device management, privacy review, backup procedures, and field validation.

The absence of a verified field dataset limits quantitative conclusions. The present paper should therefore be considered a system design and prototype-oriented research paper until experimental measurements are added.

XV. FUTURE SCOPE

Future work can include secure device authentication, MQTT telemetry, offline-first collection software, mobile applications, automated anomaly detection, demand forecasting, route optimization, and machine-learning-based quality assessment. A field study can compare the proposed workflow with existing manual processes using predefined metrics. Integration with validated dairy laboratory procedures can improve the reliability of quality-related decisions.

XVI. CONCLUSION

This paper presented a Smart Integrated System for Milk Collection and Distribution combining RFID identification, IoT sensing, ESP32-based data acquisition, server-side processing, database management, web dashboards, payment records, inventory monitoring, and milk distribution. The architecture creates a connected digital trail from supplier identification and collection to storage and downstream dispensing. It provides a practical foundation for improving traceability and operational visibility in dairy workflows. Before production deployment or quantitative claims are made, the system should be evaluated with calibrated sensors, controlled experiments, security testing, and field trials.

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