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International Journal on Advanced Electrical and Computer Engineering

ISSN: 2349-9338

Volume 15 Issue 01, 2026

IoT-Based Smart Dairy Farm Monitoring and Management System

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Peer Review Information

Submission: 18 April 2026

Revision: 09May 2026

Acceptance: 26 May 2026

Keywords

Smart Dairy Management System, IoT-Based Dairy Monitoring, Milk Collection Automation, Cattle Health Monitoring, Real-Time Data Tracking, Financial Record Management, Smart Agriculture Systems.

Abstract

Smart Dairy Management System is designed to modernize traditional dairy operations by using digital tools and IoT-based technologies. It offers a unified platform to manage milk collection, cattle health, feeding schedules, financial records, and inventory. The system removes the drawbacks of manual record-keeping, inconsistent reporting, and the absence of real-time monitoring. Through dashboards, sensors, and alert mechanisms, it improves milk tracking, automates billing, and supports data-driven decisions. Farmers can monitor cattle health, maintain hygiene, manage feed requirements, and track expenses more efficiently. Overall, the system encourages transparency, sustainability, and profitability in dairy practices, supporting India's growing shift toward smart agricultural solutions.

Introduction

The dairy industry is a vital part of the agricultural economy and provides livelihood to millions of small and marginal farmers. Dairy cooperatives form the backbone of this system by collecting milk from farmers, processing it, and ensuring payments are distributed on time. Traditionally, these operations have depended on handwritten records, paper receipts, and manual calculations. Although these methods are familiar, they are slow, vulnerable to human error, and unable to meet the increasing demands of a growing and competitive dairy market. Tasks such as calculating payments based on milk quantity and quality especially fat and SNF values are repetitive and time-consuming, often resulting in mistakes, delays, or disputes that weaken farmer confidence. With digital technology becoming more accessible, there is a strong need for a modernized system that can streamline dairy operations and improve accuracy. A centralized web-based platform can automate routine tasks, maintain reliable data, and give both farmers and administrators real-time updates on daily activities. The Smart Dairy Management System is designed to address these long-standing challenges by replacing manual, paper-driven workflows with an efficient and transparent digital solution. This system aims to integrate essential functions of a dairy cooperative, including milk collection, payment calculation, quality tracking, record management, expense monitoring, and report generation, into a single

online platform.

Literature Review

The digitization of agricultural practices, including dairy farming, has been a subject of considerable research and development. A review of existing literature and commercial products reveals a spectrum of solutions, ranging from simple record-keeping software to sophisticated enterprise resource planning (ERP) systems.

1. Ghodake R., et al. (2024) – "Smart Dairy Management System", IJNRD Discusses the role of smart dairy solutions in ensuring productivity and sustainability using real-time ICT systems. Their system monitors milk output and cow health, but lacks predictive analytics and financial integration.
2. Smith et al. (2021) – "IoT in Dairy: Milking the Benefits" Uses RFID and sensor networks for monitoring cow movement and udder health. Achieved 22% improvement in milk yield via early disease detection. Focuses only on milking automation.
3. Kale & Kulkarni (2020) – "Cloud-Based Dairy Farm Management" Developed an app-based farm management tool for milk tracking and cattle data. Found limitations in multi-user role access and offline support.
4. Patil et al. (2019) – "Feeding Optimization using AI in Dairy" Explored AI algorithms for predicting best feed times and types. Reported 18% feed cost reduction and better digestion cycles. No integration with inventory modules.
5. Global Dairy Tech Review (2023) Reviews top global solutions like DeLaval and Lely. Highlights high cost and complexity of foreign systems, emphasizing the need for affordable, scalable Indian alternatives like our.

Problem Statement

The lack of an integrated, real-time, and user-friendly system for managing dairy farm operations leads to significant inefficiencies, data inaccuracies, and delayed payments. This impacts the profitability and sustainability of both farmers and the dairy cooperative. Key problems include:

- Data Inaccuracy: Manual data entry is susceptible to human error, leading to incorrect records of milk quantity, quality, and financial transactions.
- Inefficient Processes: Manual calculation of payments and generation of reports are time-consuming and labor-intensive, diverting resources from more strategic activities. - Lack of Transparency: Farmers often lack immediate access to their collection records and payment details, which can lead to mistrust and disputes.
- Poor Scalability: Paper-based systems are difficult to scale as the number of farmers or the volume of milk collection increases.
- Limited Insights: Manual records make it nearly impossible to perform data analysis for identifying trends, optimizing collection routes, or making informed business decisions.

Proposed System

The proposed system aims to reliably differentiate between human and AI-generated speech using an offline audio analysis framework. It takes pre-recorded audio files as input and processes them through a structured pipeline to ensure high accuracy and consistency. Initially, the audio undergoes preprocessing steps such as resampling, noise filtering, silence trimming, and amplitude normalization to standardize the input.

After preprocessing, the system extracts key acoustic features, including Mel-Frequency Cepstral Coefficients (MFCCs), chroma features, spectral characteristics, and energy-related parameters. These features capture both temporal and frequency-based properties of the audio signal.

The extracted features are then provided to classification models such as Random Forest and Convolutional Neural Networks (CNNs). To improve performance and reliability, an ensemble technique can be applied to combine outputs from multiple models, resulting in more robust predictions.

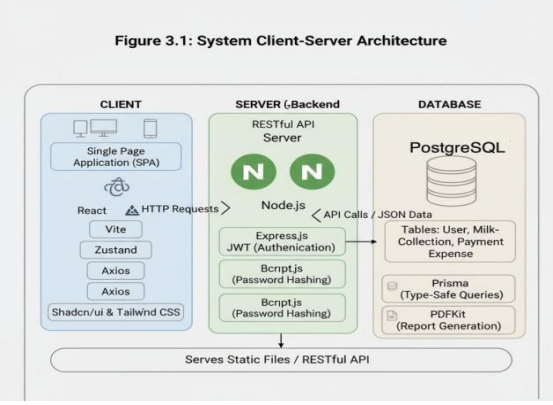
In addition, the system incorporates a sentiment analysis component that evaluates the emotional tone of user input (text or speech), categorizing it into positive, negative, or neutral classes.

The final output of the system includes both the authenticity classification (human or AI-generated voice) and sentiment interpretation, making it applicable in areas such as cybersecurity, digital forensics, and intelligent interaction systems.

Methodology

The Smart Dairy Management System is designed using a client-server architecture, which decouples the frontend (client) from the backend (server). This separation of concerns allows for independent development, deployment, and scaling of each component.

System Architecture



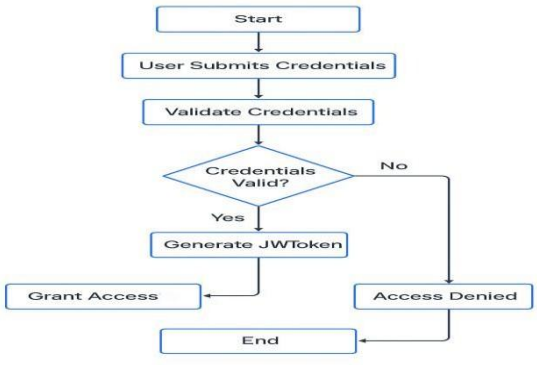
The Smart Dairy Management System is built using a client– server architecture, where the user interface and the backend logic function independently. This separation makes the system easier to scale and maintain.

Client (Frontend): The frontend is developed as a Single Page Application using React. It manages all user 'interactions, updates view dynamically, and communicates with the backend through REST API calls.

Server (Backend): The backend is developed using Node.js with Express.js. It handles core activities such as authentication, request validation, business logic execution, interactions with the database, and generating PDF reports.

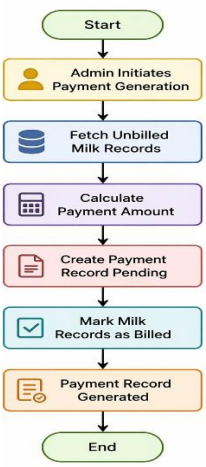
Database: All system data is stored in a PostgreSQL database. Prisma ORM acts as a type-safe and developer-friendly interface between the server and the database.

User Authentication Workflow Diagram



The entered credentials are correct, the system generates a JSON Web Token (JWT), which is used for secure and stateless authentication in subsequent requests. After successful token generation, access is granted to the user, allowing them to interact with protected resources within the system.

Data Flow Diagram



The diagram represents the flow of data during the payment generation process. It starts when the admin initiates the payment process. The system then retrieves all unbilled milk collection records from the database. Based on these records, the system calculates the payment amount using predefined rules such as quantity and quality parameters.

After calculation, a payment record is created with a pending status. The corresponding milk records are then updated and marked as billed to avoid duplication. Finally, the system generates the payment record, completing the process.

Technologies and Tools

The technologies used in this project are chosen for their performance, scalability, ease of development, and stable community support.

Backend Technologies:

- Node.js: Provides a fast and event-driven environment for server-side development.
- Express.js: A lightweight but powerful framework that simplifies building API routes and backend logic.
- PostgreSQL: A reliable and feature-rich relational database suitable for structured data handling.
- Prisma ORM: Offers a clean and type-safe way of working with the database, reducing errors and improving productivity.
- JWT (JSON Web Tokens): Enables secure, stateless authentication for users.
- Bcrypt.js: Used to hash passwords, ensuring secure credential storage.
- PDFKit: Handles PDF generation for reports such as farmer payment statements.

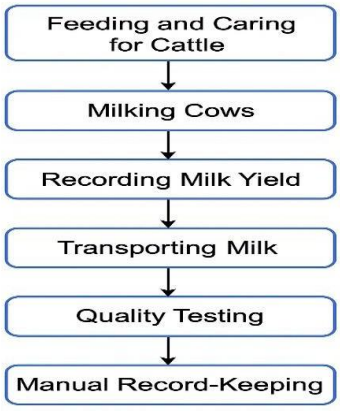
Frontend Technologies:

- React: Provides a reusable, component-based UI structure and smooth user experience.
- Vite: Ensures a fast development environment and optimized build output.
- React Router: Manages client-side navigation across pages.
- Zustand: A lightweight and efficient state management library.
- Axios: A simple HTTP client for sending API requests.

Database Schema

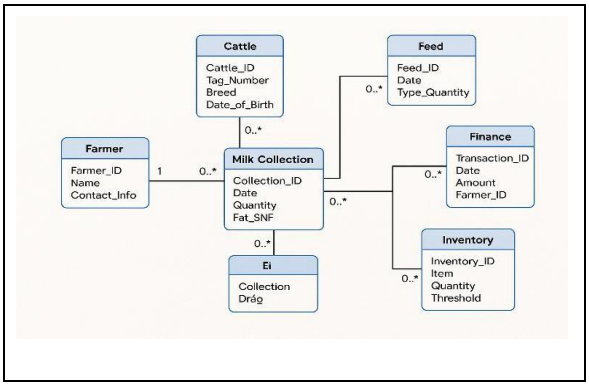
User: Contains basic user information such as name, email, password hash, and assigned role (Admin or Farmer).
Milk Collection: Stores details of each milk entry, including quantity, fat percentage, SNF value, and a reference to the farmer's ID.
Payment: Stores calculated payment details, billing periods, total amount, payment status, and links to the respective farmer.
Expense: Records all operational expenses with fields for category, amount, and description.

Traditional Dairy Operation Workflow



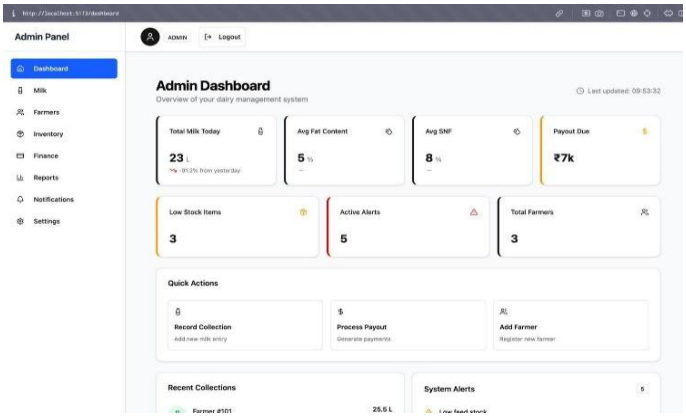
The diagram illustrates the step-by-step process followed in traditional dairy operations. It begins with feeding and caring for cattle to ensure their health and productivity. Next, cows are milked, and the milk yield is recorded manually. The collected milk is then transported to collection centers or processing units.
After transportation, the milk undergoes quality testing to check parameters such as fat and purity. Finally, all data related to milk quantity and quality is maintained through manual record-keeping methods.

Entity Relationship of Database Diagram



The diagram represents the database structure of the Smart Dairy Management System and shows how different entities are related to each other.
The main entity is **Milk Collection**, which acts as a central link between other components of the system. It stores details such as collection ID, date, quantity of milk, and quality parameters like fat and SNF.
The **Farmer** entity contains information about farmers, including farmer ID, name, and contact details. One farmer can have multiple milk collection records (one-to-many relationship).

Result Analysis



The Admin Dashboard provides a centralized interface for managing and monitoring the overall operations of the Smart Dairy Management System. It displays key metrics and essential information in a structured and user-friendly format.

At the top, the dashboard shows important statistics such as total milk collected for the day, average fat content, average SNF, and the total payout due. These metrics help the administrator quickly understand daily production and financial status.

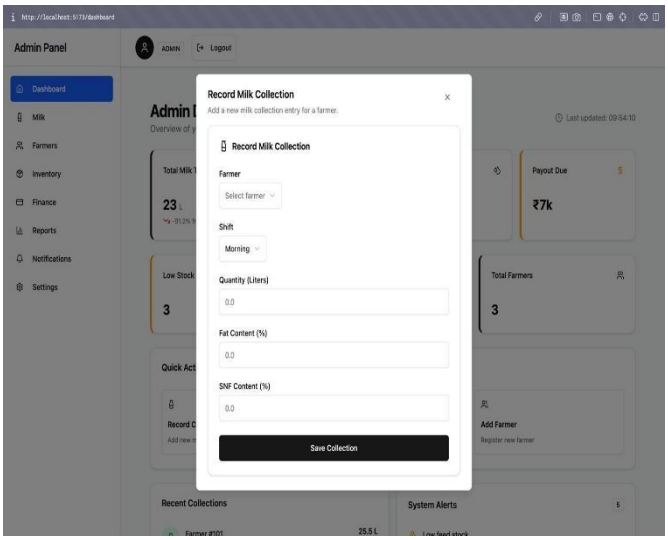
Below this, additional indicators such as low stock items, active alerts, and total number of farmers are displayed. These sections assist in tracking inventory levels, identifying system warnings, and managing farmer data efficiently.

The dashboard also includes a "Quick Actions" section, allowing the admin to perform key tasks such as recording milk collection, processing payouts, and adding new farmers directly from the main screen.

Further sections like recent collections and system alerts provide real-time updates, helping the admin stay informed about ongoing activities and potential issues.

Overall, the dashboard enhances decision-making by providing real-time insights, improving operational efficiency, and ensuring smooth management of dairy activities.

The preprocessing stage also played a critical role in improving system performance. Techniques such as noise reduction, silence trimming, and amplitude normalization ensured that the input data was clean and standardized. By removing irrelevant components and minimizing distortions, the system was able to focus on meaningful speech characteristics. This resulted in improved feature consistency and allowed the model to learn more accurate patterns during training.



The image shows the **Milk Collection Form** used in the Smart Dairy Management System for recording daily milk entries. This form allows the administrator to input and store milk collection data for each farmer.

The admin first selects the **farmer** from a dropdown list and chooses the **shift** (e.g., morning or evening). Then, the quantity of milk collected (in liters) is entered. The form also includes fields for **fat content (%)** and **SNF content (%)**, which are important quality parameters used for payment calculation.

Once all details are filled, the admin can submit the form by [1] Rohan Ghodake, Om Ranaware, Vaibhav Rane, and clicking the "Save Collection" button. The data is then sent to the backend, validated, and stored in the database. This form ensures accurate data entry, supports real-time record management, and helps automate the calculation of payments based on milk quality and quantity

Challenges And Limitations

The proposed Smart Dairy Management System faces several challenges related to data accuracy and real-time data collection. Since the system relies on inputs provided by users or sensors, inconsistencies may arise due to human error, incorrect entries, or faulty sensor readings. In rural environments, where digital literacy may be limited, users might enter incomplete or inaccurate data, affecting the overall reliability of the system. Additionally, external factors such as network connectivity issues can delay real-time updates, reducing system efficiency in remote areas.

Another significant limitation is related to system scalability and dependency on technology

infrastructure. As the number of farmers and data volume increases, the system must handle large-scale data processing efficiently. Without proper optimization, performance issues such as slow response time and increased server load may occur. Moreover, the system depends heavily on internet connectivity and server availability, which can be a challenge in areas with unstable network conditions. Integration with IoT devices, if implemented, may also introduce additional complexity in terms of maintenance and cost.

Furthermore, there are challenges associated with data security and system adaptability. The system stores sensitive information such as financial records and user details, making it vulnerable to security threats if not properly protected. Ensuring secure authentication and data encryption is essential but may increase system complexity. In terms of adaptability, the system may require regular updates to incorporate new features, changing business requirements, or technological advancements. Additionally, while analytical features provide useful insights, they may not always capture complex real-world conditions such as sudden changes in milk production due to environmental or health factors. These limitations highlight the need for continuous improvement and system optimization for better real-world performance.

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