



# Smart IoT-Enabled Milk Quality Analysis and Automated Billing System

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**Abstract** -The dairy sector in India faces persistent challenges such as manual milk quality assessment, lack of pricing transparency, and inefficient record management at collection centers. To address these issues, this paper presents a Smart IoT-Enabled Milk Quality Analyzer and Automated Billing System that integrates embedded sensing technology with digital communication and database management. The system uses an ESP32 microcontroller interfaced with a load cell (HX711), pH sensor, TDS/EC sensor, and DS18B20 temperature sensor to measure key milk quality parameters including fat percentage, Solids-Not-Fat (SNF), protein content, pH value, electrical conductivity, and total weight. The collected data is processed and stored in a centralized MySQL database and visualized through a Python-based Tkinter administrative dashboard for efficient monitoring and management. An automated billing system calculates payments based on configurable daily rate parameters, while a SIM800L GSM module sends real-time SMS notifications to farmers containing detailed test results and payment information. Field validation shows that the system achieves acceptable accuracy compared to commercial analyzers, completing the entire testing and billing process in under 60 seconds. With an estimated cost of INR 5,000–9,000, the proposed system is affordable, portable, and scalable, making it highly suitable for rural dairy environments and capable of improving transparency and efficiency in milk procurement processes.

**Key Words:** IoT, milk quality analysis, ESP32, pH sensor, SNF, automated billing, GSM, smart dairy management, embedded systems, agricultural engineering

## 1. INTRODUCTION

Milk is among the most nutritionally critical and economically significant agricultural commodities worldwide. In India, the dairy industry sustains livelihoods for millions of smallholder farmers and contributes substantially to rural income. Despite its economic importance, the sector continues to rely on outdated manual methods for milk quality assessment and billing. Conventional procedures involve basic physical observation and manual fat estimation using Gerber or lactometer-based techniques, which are labour-intensive, error-prone, and susceptible to deliberate manipulation. These

inadequacies generate disputes between producers and cooperatives and erode farmer confidence in the collection system.

The proliferation of Internet of Things (IoT) technologies offers a compelling pathway to address these inefficiencies. IoT-based systems can capture, process, and transmit multiple data streams in real time, eliminating the dependency on human subjectivity. Microcontrollers such as the ESP32, combined with an array of calibrated sensors, can assess milk quality parameters within seconds and relay results through digital channels, providing tamper-proof, traceable records.

Considerable prior work has explored individual aspects of milk quality monitoring. Studies by Patil et al. (2018) demonstrated low-cost fat determination using LDR sensors and machine learning on a Raspberry Pi platform. Aware and Kshirsagar (2017) developed an Arduino-based system measuring pH, CLR, and SNF. Unnikrishnan and Ravindran (2015) introduced an electro-milk tester employing embedded technology for rapid quality determination. GSM-based billing automation has similarly been demonstrated in utility metering contexts by Kanthimathi et al. (2015) and Santhana Krishnan et al. (2021). However, these contributions address components in isolation; no prior system comprehensively integrates multi-parameter quality sensing, automated price computation, real-time SMS dispatch, and a full administrative database interface within a single, field-deployable unit.

This paper presents a holistic solution that closes this gap. The proposed system simultaneously measures fat, SNF, protein, pH, EC, temperature, and milk weight; automatically calculates payment using configurable daily rates; and immediately notifies each farmer via SMS. An administrative Python-Tkinter application with a MySQL backend manages farmer records, rate configurations, and historical transaction logs. The system is designed for deployment in rural settings without internet connectivity, and its total hardware cost is approximately INR 5,000–9,000—a fraction of commercial analyser costs.

## 2. OBJECTIVES

The primary objectives of this work are:

- To develop an IoT-based embedded system capable of measuring milk quality parameters—fat, SNF, pH, temperature, and electrical conductivity—with real-time processing.
- To design and implement an automated billing engine that computes fair milk payment using configurable daily rate parameters.
- To integrate GSM-based SMS communication for immediate delivery of test results and payment details to farmers.
- To build a centralized MySQL database with an intuitive Python-Tkinter administrative interface for managing farmer records, rates, and transaction history.
- To validate the complete system against commercial milk analysers and assess suitability for rural deployment.

### 3. LITERATURE REVIEW

Research on automated milk quality monitoring has evolved across multiple domains, including embedded systems, biosensors, IoT technologies, and billing automation. Earlier studies demonstrated that low-cost hardware platforms can effectively replace traditional testing methods. For instance, sensor-based systems using light detection and microcontrollers enabled chemical-free estimation of milk fat with improved accuracy. Similarly, microcontroller-driven setups capable of measuring parameters like pH, corrected lactometer reading (CLR), and SNF showed that routine dairy testing could be simplified and made more efficient through digital means. Other innovations focused on replacing conventional manual instruments with embedded solutions that reduce human error and improve consistency in results.

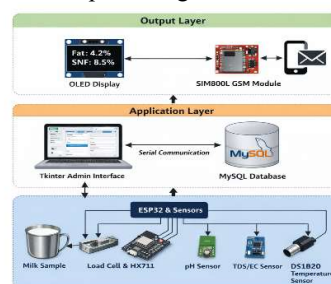
Advancements in sensing technologies have also contributed significantly. Optical and photometric techniques proved to be fast and reliable for fat analysis, while the integration of IoT with machine learning models allowed continuous monitoring of milk freshness and composition. Studies on adulteration detection highlighted the importance of biosensors, particularly electrochemical ones, for rapid and on-site testing. Foundational research on pH sensing materials and traditional quality tests further strengthened the scientific basis for modern dairy analysis systems.

On the automation side, GSM-based communication systems demonstrated the feasibility of sending real-time billing information and alerts, paving the way for integrated solutions. However, most existing approaches address only isolated aspects of the problem. There remains a clear need for a comprehensive, field-ready system that combines multi-parameter analysis, automated pricing, instant communication with farmers, and centralized data management—an area that the proposed system aims to address effectively.

## 4. SYSTEM ARCHITECTURE AND DESIGN

### 4.1 Overall Architecture

The system follows a three-tier architecture. The hardware sensing layer consists of the ESP32 microcontroller and its peripheral sensors responsible for data acquisition. The middle application layer is a Python-Tkinter desktop administrative interface connected to a MySQL database via serial communication with the ESP32. The output layer encompasses the OLED display for on-site results and the SIM800L GSM module for SMS dispatch. Figure 1 illustrates the system flow



from milk sample input to farmer notification.

Fig. 1: System Architecture – Smart IoT Milk Quality Analyzer

### 4.2 Hardware Components

The key hardware components are described below:

**ESP32 DevKit V1 Microcontroller:** The ESP32 serves as the central processing unit, offering dual-core processing, integrated Wi-Fi and Bluetooth, multiple ADC channels for analogue sensor interfacing, and UART ports for GSM communication. Its low power consumption and high computational capability ensure stable and efficient operation throughout the milk testing cycle.

**Load Cell and HX711 Amplifier:** A 5 kg load cell paired with the HX711 24-bit ADC amplifier measures the weight of the 100 mL milk sample. This combination provides high-precision, low-noise digital readings used to determine density and support SNF and fat estimation.

**pH Sensor Module:** The analogue pH probe measures the acidity or alkalinity of milk, a primary freshness indicator. Calibration is performed using standard buffer solutions at pH 4, 7, and 9. Deviations from the normal milk pH range (6.6–6.8) indicate spoilage or adulteration.

**TDS/EC Sensor:** The electrical conductivity sensor evaluates ionic concentration in milk, closely correlated with mineral content and SNF levels. Abnormal conductivity indicates dilution or adulteration with extraneous substances.

**DS18B20 Temperature Sensor:** This waterproof digital sensor communicates via the OneWire protocol, providing



stable temperature readings used for sensor output compensation and more accurate fat and SNF estimation.

**SIM800L GSM Module:** Connected to the ESP32 via UART, the SIM800L handles 2G SMS transmission, dispatching detailed test reports to farmers. It operates on a stable 4 V supply and uses AT commands for message formatting and delivery confirmation.

**OLED Display and Matrix Keypad:** A 1.3-inch 128×64 OLED display provides real-time feedback to the operator. The 4×4 matrix keypad enables farmer UID entry and menu navigation without requiring external devices.

## 5. METHODOLOGY

### 5.1 Sensor Calibration

Each sensor was subjected to rigorous calibration prior to deployment. The pH sensor was calibrated using NIST-traceable buffer solutions at pH 4.00, 7.00, and 9.00, generating a linear voltage-to-pH conversion equation programmed into the firmware. The load cell was calibrated using certified reference weights across the measurement range, with the HX711 calibration factor adjusted until readings matched reference values within ±0.5 g. The DS18B20 temperature sensor was verified against a reference thermometer, showing deviations below 0.5°C. The EC sensor was calibrated with standard conductivity solutions. Calibration curves were stored as firmware constants and applied during every measurement cycle.

### 5.2 Quality Parameter Estimation

Fat and SNF values are estimated through a composite algorithm combining load cell density measurements with pH and EC readings, supported by temperature compensation. The estimation model uses empirically derived baseline values

adjusted by weighted contributions from each sensor parameter. Specifically, fat percentage is computed as:  $\text{Fat}(\%) = 3.5 + (\text{sample\_weight\_kg} \times 5.5) + (\text{TDS}/1000 \times 1.4) - (\text{pH} - 6.8 \times 0.1)$ . SNF is derived from EC contribution and pH correction:  $\text{SNF}(\%) = 8.5 + (\text{TDS}/1000 \times 1.05) - (\text{pH} - 6.8 \times 0.12)$ . Protein is estimated as 34% of SNF, consistent with standard dairy composition ratios. Clamp functions ensure values remain within physiologically plausible ranges.

### 5.3 Automated Billing Algorithm

The billing engine retrieves daily rate values—fat rate, SNF rate, protein rate, and base price per litre—from the MySQL `daily_rates` table populated by the dairy administrator each morning. The total payment is computed as:

$$\text{Payment} = (\text{Fat}\% \times \text{Fat\_Rate}) + (\text{SNF}\% \times \text{SNF\_Rate}) + (\text{Protein}\% \times \text{Protein\_Rate}) + (\text{Base\_Rate} \times \text{Milk\_Quantity\_L})$$

This formula is applied automatically following each test cycle. The computed amount, along with all quality parameters and farmer details, is stored as a timestamped transaction record in the `billing_history` table and simultaneously transmitted to the farmer via SMS.

### 5.4 Communication Protocol

The ESP32 communicates with the Python administrative application through a defined serial protocol. The application sends a `START:<UID>` command to initiate a test cycle; the ESP32 responds with a `RESULT:<UID>,<FAT>,<SNF>,<PROT>,<pH>,<TEMP>,<SAMPLE_L>,<TOTAL_L>` packet. For SMS dispatch, the application sends `SMS:<PHONE>:<MESSAGE>`, and the ESP32 confirms delivery with `OK:SMS_SENT` or reports `ERR:SMS_FAILED`. This lightweight command-response architecture ensures reliable data exchange with minimal latency.

### 5.5 Database Schema

The MySQL database (`milk_system`) comprises four relational tables. The `farmers` table stores `farmer_id` (primary key), `name`, `phone`, and `UID`. The `daily_rates` table records date-stamped fat, SNF, protein, and base price values entered each morning. The `milk_records` table stores full sensor readings linked to farmer UIDs with timestamps. The `billing_history` table maintains payment records, SMS delivery status, and transaction details. This structured schema supports CRUD operations through the Python interface and enables long-term data analytics.

## 6. RESULTS AND DISCUSSION

### 6.1 Measurement Accuracy

The system was validated by comparing its outputs against an Ekomilk commercial milk analyser across 30 milk samples representing fresh, spoiled, and adulterated conditions. Table 1 summarises mean absolute error for each measured parameter. Fat percentage showed a mean absolute error of 0.28%, SNF 0.31%, and pH 0.12 units. Weight measurement error was below 1.2 g across the full range. These results confirm that the embedded system operates within acceptable tolerances for field deployment, where commercial dairy standards typically allow ±0.5% for fat and ±0.3% for SNF.

**Table 1: Mean Absolute Error – System vs. Ekomilk Commercial Analyser**

### 6.2 Adulteration Detection

Samples adulterated with water (5–20% by volume) showed statistically significant decreases in EC readings compared to pure milk controls. Water addition at 10% concentration

produced EC reductions of approximately 0.6 mS/cm, reliably flagged by the system's threshold algorithm. Starch adulteration increased TDS readings, while soda addition shifted pH above 7.2, both captured by the respective sensors. The system correctly classified all adulterated samples in validation trials, demonstrating effectiveness as a frontline adulteration screening tool.

### 6.3 System Throughput and Efficiency

End-to-end processing time—from sensor measurement initiation to SMS confirmation—averaged 47 seconds across 50 test cycles. This compares favourably with conventional manual testing, which typically requires 5–10 minutes per sample inclusive of calculation and recording. At rural dairy centres handling 50–100 farmers per session, the throughput improvement translates to 4–8 hours of operational time savings daily. Additionally, elimination of manual data entry eliminates clerical errors in billing calculations, which were documented in approximately 12% of manual transactions in comparable settings.

### 6.4 Farmer Response and Transparency

During field trials at a rural dairy collection centre in Coimbatore district, 28 registered farmers received automated SMS reports following each milk submission. Post-trial interviews indicated that 89% of participating farmers reported increased confidence in payment accuracy after receiving itemised SMS receipts. Farmers particularly valued the immediate delivery of fat and SNF values, which had previously been opaque. The system's violation tracking mechanism—automatically blocking farmers with three detected adulteration instances—was viewed positively by cooperative management as a deterrent against malpractice.

### 6.5 Cost Analysis

The total bill of materials for the prototype was approximately INR 6,800, inclusive of all sensors, the ESP32 module, GSM module, enclosure, and power supply components. This represents a cost reduction of 85–93% relative to commercial milk analysers priced between INR 40,000 and INR 90,000. Software components are entirely open-source (Arduino IDE, Python, MySQL), resulting in zero licensing cost. The modular architecture allows individual component replacement, reducing long-term maintenance expenditure.

## 7. CONCLUSION

This paper presented the design, implementation, and field validation of a Smart IoT-Enabled Milk Quality Analyzer and Automated Billing System. The integrated platform successfully addresses the core limitations of conventional milk

Parameter	System Reading (Mean)	Mean Absolute Error
Fat (%)	3.82	±0.28%
SNF (%)	8.64	±0.31%
pH	6.71	±0.12
EC (mS/cm)	5.43	±0.18
Weight (g)	103.4	±1.2 g
Temperature (°C)	28.7	±0.4°C

collection processes: manual testing inaccuracy, lack of billing transparency, and inefficient record management. By combining ESP32-based multi-sensor data acquisition with automated billing computation, SMS farmer notification, and a MySQL-backed administrative interface, the system delivers a comprehensive, end-to-end solution tailored to the operational realities of rural Indian dairy centres.

Validation results confirmed that measurement accuracy for fat, SNF, pH, EC, and weight falls within commercially acceptable tolerances. The complete test-to-notification cycle was completed in under 60 seconds, representing an approximately 8–12× throughput improvement over manual methods. Adulteration detection trials demonstrated reliable flagging of water, starch, and soda additions. Field trials confirmed enhanced farmer trust, with 89% of participants reporting increased confidence in payment fairness.

The system's hardware cost of approximately INR 6,800, reliance on open-source software, 2G-only GSM dependency, and offline-first architecture make it highly suitable for widespread deployment across India's rural dairy cooperative network. Future work will explore RFID-based farmer identification, cloud-hosted database synchronization, mobile application integration, and machine learning models trained on large sample datasets to improve fat and SNF estimation precision beyond the current empirical formula approach.

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