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IoT-Driven Milk Adulteration Detection System

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***Abstract*— The adulteration of milk is one of the major challenges to food safety, as the addition of adulterants affects its nutritional quality. Traditional methods for detection have remained dominantly laboratory-based and hence not suitable for real-time procurement environments. This paper proposes an IoT-enabled milk quality assessment system, comprising sensors such as temperature, pH, electrical conductivity, turbidity, and RGB color. The data from multiple sensors is processed to calculate a milk purity percentage, which is used to create a pricing recommendation that will be transparent and unbiased toward the farmers. The proposed system will introduce greater accountability and enhance trust along the value chain of dairy products, thereby offering a scalable solution for intelligent monitoring of the quality of milk.**

***Keywords*— Internet of Things (IoT), Real-time monitoring/evaluation, Multiple Sensors, Sensor Integration, System Design, Requirement Specifications.**

I. INTRODUCTION

Milk is an extremely important food commodity consumed globally and is a good source of protein, calcium, and many key nutrients that are required for the development and well-being of all individuals. Owing to the high nutritional and economic value associated with it, milk is one of the most adulterated food commodities. With the rising demand for milk, especially in the emerging markets with more complicated supply chains, the issue of milk adulteration has worsened.

The primary cause for milk adulteration is economic, where the volume can be expanded or poor-quality milk can be masked for greater economic gain. Moreover, there can be several methods involved in milk adulteration, which may range from simple water mixing, resulting in reduced nutritional value, to the addition of toxic chemical substances. The common chemical substances involved in milk adulteration are detergent substances, starch, urea, caustic soda, and hydrogen peroxide.

Consuming Adulterated milk can cause serious health issues such as gastrointestinal problems and organ failure. This has led to a lack of trust in milk among the current population and has resulted in the dairy industry suffering losses. There is a great need for a rapid milk adulteration analysis solution to check the quality of milk at the procurement stage. This study aims to develop a solution for the above-mentioned issue.

A. Limitations of Conventional Quality Control

Adulteration of milk is a serious issue that demands stringent quality control. The conventional method of milk quality determination involves laboratory tests such as the Gerber test, lactometer test, and chemical reagent test. Although accurate results can be obtained by such tests, their requirements of properly equipped laboratories and highly skilled personnel, in terms of time and costs, make such tests unsuitable.

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In countries with a decentralized milk collection chain, there is a certain time lapse between milk collection and testing, allowing contaminated milk to find its way into the chain, thereby making it difficult to trace its origin due to its large quantities. Further, traditional approaches analyze each contaminant individually and do not offer a quick overview of milk quality.

Therefore, there is a requirement for a solution that is rapid, inexpensive, and able to analyze milk quality in real time when collected.

B. The Proposed Paradigm Shift: An IoT-Enabled Solution

In order to overcome some of the limitations associated with conventional testing, this project describes an IoT-based milk quality monitoring system in real time at a collection point. This integrated approach embeds several sensors into one unit to provide real-time, all-around quality assessment.

This sensor module incorporates a temperature sensor for storage conditions, a pH sensor to detect abnormal levels of acidity or alkalinity, an electrical conductivity sensor to trace the presence of dissolved adulterants like salt or urea, a turbidity sensor for measuring the cloudiness caused by adulterants like starch, and an RGB color sensor to detect abnormal color variations.

Combined sensor data are then processed to provide an overall milk purity percentage-a reliable and quantitative measure of milk quality beyond traditional pass/fail testing.

C. Project Scope, Impact, and Document Structure

The result obtained will not only be used for detecting traces of adulteration but also for ensuring economic transparency. Based on the scientifically obtained purity percentage, a system will be designed that will recommend a fair price that should be paid for obtaining such products from farmers.

II. LITERATURE SURVEY

Sharma et al. (2020) developed an IoT system for detecting milk adulteration in real time using basic embedded pH and conductivity sensors, although their study lacked comprehensive detection capability by not considering turbidity and color sensors.

The "IoT based food quality analysis" study by Kumar & Reddy (2019) was published via Springer and focused on using the Internet of Things for expanding the monitoring of perishable foods. The basis of their method was to deploy pH and temperature sensors for tracking spoilage. In this approach, the temperature sensor assesses conditions of storage, while the pH sensor flags rising acidity linked with microbial spoilage. Although useful in the assessment of freshness and handling, the research was mainly confined to the detection of natural spoilage-that is, the passive degradation of food, which renders it less able to address the complex markers of deliberate chemical adulteration.

Gupta et al. (2021), in "A novel approach to detect urea in milk" on ScienceDirect, presented a highly specific technique of detecting the presence of urea in milk by reagent-based optical detection and colorimetry, but this technique remained limited to testing only one parameter and did not have a wide scope for overall, multi-contaminant milk quality assessment.

Mehta & Singh (2018), "Smart dairy monitoring system" on IEEE Xplore, proposed a cloud-based milk monitoring system using sensors integrated with wireless communication to transmit quality data to the central server. However, this system provided remote surveillance and data logging in the dairy supply chain but lacked the integration of pricing mechanisms and, hence, could only monitor quality and not facilitate a data-driven cost settlement between the farmers and cooperatives.

The research work "Machine learning in milk quality prediction" by Rani et al. (2022), published via Springer, aimed at developing an approach to classify and predict milk adulteration using ML models on existing sensor data. The researchers developed ML-based classification models successfully with strong results in terms of data analysis. However, the main challenge was the lack of any real-time mobile integration; this means the system lacked the crucial element of instantly displaying the results and cost settlement data to users at the collection point.

The work of Das et al. (2021), "Turbidity-based adulteration detection" on ResearchGate, focused on the use of turbidity sensors to provide detection and quantification of water dilution in milk by observing changes in clarity. Although real-time turbidity measurement was successfully implemented in this study, it was limited to a single optical parameter and did not combine the measurement with chemical sensors such as pH or EC; hence, this system could detect only dilution and was not able to identify chemical contaminants.

The work of Khan et al. (2020), "Portable analyzer for dairy cooperatives" on Elsevier, consisted of a handheld, multi-sensor portable prototype designed for easy field use by dairy cooperatives. While this device achieved portability and multi-sensor capability, it was eventually introduced as a closed-source, proprietary solution that significantly limits its general academic scrutiny, customizability, and open-source deployment critical for low-cost scalability.

Patel et al. (2021), in "Blockchain-based milk supply chain" on the ACM digital library, integrated Blockchain with IoT devices for immutability and authenticity of data through a distributed ledger. Though this is highly effective for securing data and increasing traceability, the intrinsic complexity in implementing Blockchain makes the system less inclusive and not intrinsically farmer-friendly at the grassroots level of the dairy supply chain.

Rai et al. (2019), in a study covered by Nature.com, conducted advanced milk adulterant detection using optical spectroscopy. The main idea was the spectral "fingerprinting" of milk samples to identify the unique signatures of contaminants. It allows for very accurate, non-destructive analysis, but because the spectroscopy hardware is specialized, the solution will have a high cost and complex instrumentation, hence unsuitable for low-cost, grassroots, real-time field deployment.

The research by Thomas & George (2022), entitled "Comparative analysis of milk adulteration methods" on Wiley, presented a detailed survey and literature review of various existing adulteration detection methods; the pros and cons of each technique were elaborated with due care. However, the analytical study did not propose or implement any practical real-time solution or propose any novel hardware system; thus, it remains a foundational research summary.

III. Problem Statement

Milk adulteration creates problems in the dairy industry as well.

The adulterants used in milk include water, starch, detergents, soda, and urea, which increase the quantity and apparent quality of milk.

This creates the following problems:

- Compromised nutritional value and health risks to consumers.
- Mistrust between farmers and cooperative societies because of disputes over the quality of milk.
- Most of the quality checks depend on laboratories, which delays decision-making.
- Small-scale farmers' lack of awareness and unavailability of affordable testing mechanisms.

The need of the hour is, therefore, a portable automated solution that can detect adulteration in real time and ensure that A pricing mechanism based on transparency of milk purity.

A. Project Objectives Descriptions

- The design and development of a multi-sensor hardware setup that detects different physical and chemical properties of milk relevant to adulteration.
  This covers selecting and arranging all necessary sensors for measuring temperature, pH, electrical conductivity, turbidity, and RGB color in a functional compact unit. The setup will have to be optimized to measure the specific parameters most likely to change upon the addition of common adulterants like water, starch, and detergents.
- To interface microcontrollers with sensors for real-time data acquisition and processing.
  The goal here is to interface the sensor array with a microcontroller, such as Arduino or Raspberry Pi, to ensure a high-speed continuous capture of data. A microcontroller running the appropriate code will digitize, clean, and pre-process the raw sensor data immediately upon collection
- To develop an application interface which will calculate milk purity percentage.
  The objective is to develop the software-web or mobile application that will get the preprocessed sensor data and execute a mathematical model or algorithm. This interface should clearly show the resulting quantitative purity score that results from comparing measured properties against established quality benchmarks.
- To dynamically determine the fair cost of milk supply based on the quality and purity score. Develop a logic model within the application that will translate calculated purity percentage into a recommended procurement price. The feature shall ensure the farmer is compensated for the exact quality of milk, thereby effectively linking quality assessment with economic reward.
- To promote transparency along the whole dairy supply chain and protect consumer health with low-cost, scalable technology.The deployed system has to be affordable and easy to deploy in large numbers at various points of collection so that quality testing becomes prevalent and accessible. Because the technology

provides instant, objective data, accountability and transparency are inherently enhanced; this ultimately protects the end consumer from injurious adulterated products.

IV. PROPOSED SYSTEM

The proposed system integrates seven different sensors with IoT and machine learning principles for robust, real-time, multi-parameter milk adulteration detection at the point of procurement. This expanded sensor array provides a comprehensive physico-chemical "fingerprint" of the milk sample.

A. Hardware Components

- Temperature Sensor (DS18B20 / LM35) - Reference Control & Spoilage: It gives the exact sample temperature for correcting the readings from pH, EC, and refractometer sensors so as to ensure data accuracy. It also flags abnormally high temperatures indicating spoilage or improper storage.
- Analog pH Probe: Chemical Alteration - measures acidity/alkalinity. Abnormal values will indicate the addition of neutralizers (such as caustic soda or soda ash) to mask sourness or high acidity due to microbial spoilage.
- EC / TDS Sensor Ionic Contaminants & Dilution: The sensor monitors electrical conductivity, which leaps when ionic substances such as salt, urea, or detergents are added. High TDS strongly indicates water dilution or foreign salts.
- Refractometer / Optical Sensor: Dissolved Solids & Dilution-this approach uses measurements of the refractive index (RI) of milk. The RI is highly sensitive to the concentration of dissolved solids, that is, lactose and protein. A reduced RI is a key indicator of water dilution or addition of cheap sugars.
- Turbidity Sensor (SEN0189) Suspended Impurities & Clarity: Measures light scattering to detect the concentration of suspended particles. High turbidity could indicate foreign solids, for instance, starch or powdered substances, or quantify the effects of dilution.
- Colour Sensor (TCS34725) Visual Contaminants: It captures the exact RGB spectral values of milk. It is used for detecting minute colour changes caused by adulterants, such as yellowing caused by turmeric or other colouring agents, or to read the results of simple, rapid reagent strip tests placed in the chamber.
- Load Cell + HX711: Density/Specific Gravity Check - Measures the exact weight of a fixed volume of milk that is poured into the sensor chamber. Adding this value with volume calculates directly the milk density, important for the detection and quantification of simple dilution with water.

B. Software Components

- Microcontroller: Arduino/ESP32/ESP8266 to manage the seven sensors, perform the analog-to-digital conversions, and handle the initial aggregation and transmission of data.
- Backend: Flask or Django framework, to receive the seven sensor inputs, apply the Purity Calculation Algorithm, store the data, and run the Cost Settlement Model.
- Database: MySQL on the cloud or another platform providing full traceability, allowing secure storage, tracking of records, training of machine learning, and auditing remotely.
- Frontend/Mobile App: The user interface, which will display the comprehensive results in real time, including the Purity Percentage calculated and the final Fair Price settlement value.

C. Workflow

Fig 1

- Sample Intake: A standard amount of milk is passed into the integrated multi-sensor chamber.
- Synchronous Acquisition: The microcontroller reads simultaneously from the seven sensors, T, pH, EC, Turbidity, Color, RI, and Weight/Density, recording the data.
- Data Preprocessing & Correction: Normalization of all raw readings and temperature correction of pH, EC, and RI values are done using the T-sensor data to achieve the highest accuracy.
- Multi-Parameter Validation: The system cross-validates the seven data points against known thresholds for pure milk and pre-trained patterns for common adulterants.
- Purity Calculation: The weighted algorithm calculates the final overall purity percentage based on the deviations across all seven parameters.
- Reporting & Settlement: The mobile application instantly provides the purity score and the dynamically calculated fair price to be paid to the farmer, thereby completing the transparent transaction.

V. Expected Outcomes

Real-Time Low-Cost Detection: Facilitates real time milk quality testing at collection points using real time low cost detectors.
Multi-Parameter Quality Analysis: Integrates data from a variety of sensors for better accuracy in adulteration detection and analysis.
Purity Percentage Estimation: Gives an unbiased purity percentage measurement for standardized assessment.
Data Driven Pricing Mechanism: Involves using the purity level for suggesting ethical and transparent prices during purchasing.
Increased Transparency: It leads to less disputes, as it offers instant and auditable quality information to every individual.
Quality Data Storage:
Maintains quality records for all periods to facilitate quality analysis.
Enhanced Consumer Safety: It safeguards the consumer by ensuring that no contaminated milk finds its way into the supply chain.

VI. Conclusion

The proposed project wishes to offer a transformative and effective solution to the global challenge of milk adulteration through introducing a cost-effective sensor-based IoT system for real-time quality assessment and purity verification.
The key power of this system is in the multi-parameter approach that now combines a wide-ranging set of seven sensors for temperature, pH, electrical conductivity, turbidity, color, refractometer, and load cell into one holistic physico-chemical "fingerprint" of the milk sample. This architecture is thus directly addressing several limitations present in the existing literature, which has often focused on narrow scopes of detection, with either no real-time mobile integration or high costs and complicated hardware involvement.
From mere detection, the system introduces a mechanism for economic transparency whereby, upon processing such readings through a weighted algorithm, it works out the percentage purity. This dynamic purity score forms the basis for recommending a cost that is fair and justified for procurement, thereby setting up a data-driven settlement system that fosters accountability and transparency between farmers and cooperatives.
This IoT solution will be scalable and low-cost, hence bound to revolutionize milk quality assurance through immediate and accurate detection right at the collection point. Its successful deployment is bound to protect consumers' health from harmful contaminants and restore fairness and trust in the whole value chain of dairy products.

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