Aqua Milk Detect

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***Abstract*—Aqua Milk Detect is a low-cost and portable IoT-based system designed to detect milk adulteration quickly and easily. It uses an ESP32 microcontroller and multiple sensors to measure milk properties. A trained Support Vector Machine (SVM) model identifies milk as pure or adulterated with water, detergent, or starch. The system includes a TFT display, Wi-Fi dashboard, USB communication, and an automatic flushing mechanism. If the prediction confidence is below 0.60, it displays an "Uncertain" result and recommends testing again. This system provides a simple and affordable solution for preliminary milk quality screening.**

***Index Terms*—Milk Adulteration Detection, Internet of Things (IoT), ESP32, Support Vector Machine (SVM), Sensor Integration, Machine Learning, Real-Time Monitoring.**

I. INTRODUCTION

Milk is an important food product, and maintaining its quality and purity is essential for consumer safety. Adulteration with substances such as water, detergent, and starch can affect milk quality and may cause health problems. Traditional testing methods often require laboratory equipment, trained personnel, and more time, making quick testing difficult.

The Internet of Things (IoT) and Machine Learning offer a practical approach to preliminary milk quality screening. Aqua Milk Detect uses an ESP32 microcontroller with pH, TDS, turbidity, colour, temperature, and density sensors to collect milk parameters.

A Support Vector Machine (SVM) model deployed on the ESP32 classifies milk as pure, water-adulterated, detergent-adulterated, or starch-adulterated. The system displays uncertain results when prediction confidence is low and presents the output on a TFT screen and Wi-Fi dashboard. An automatic flushing mechanism cleans the testing chamber using distilled water after each test.

II. SYSTEM DESIGN

2.1 Overall System Architecture

The Aqua Milk Detect system is designed to detect possible milk adulteration by integrating multiple sensors, an ESP32 microcontroller, and an Edge Machine Learning model. The system architecture consists of three main layers: Data Acquisition, Data Processing and Classification, and User Interaction.

A. Data Collection

The ESP32 collects milk parameters such as pH, TDS, turbidity, colour, temperature, and density using multiple sensors. Readings are averaged over approximately three seconds to improve consistency.

B. Data Preprocessing

The collected sensor values are calibrated and standardized using StandardScaler to ensure that all features are suitable for machine learning.

C. Model Training

A Support Vector Machine (SVM) model is trained using labelled sensor data to classify milk into four categories: Pure, Water-adulterated, Detergent-adulterated, and Starch-adulterated.

D. Edge ML Deployment

The trained SVM model and scaling parameters are deployed directly on the ESP32, enabling local classification without cloud processing.

E. Result Display and Cleaning

The classification result is displayed on the TFT screen and Wi-Fi dashboard. If the confidence score is below 0.60, the system displays "Uncertain – Retest."After testing, a peristaltic pump flushes the chamber with distilled water to prepare it for the next sample.

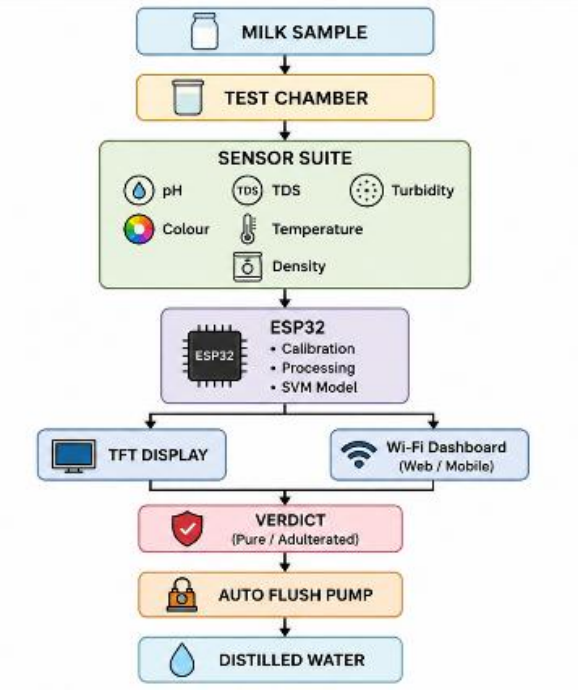

Fig. 1. System Architecture

2.2 Module Design

The Aqua Milk Detect system is divided into four main modules to simplify implementation, improve functionality, and support efficient milk adulteration screening.

1. Sensor Data Acquisition Module:

This module is responsible for collecting real-time data, calibration of the sensor, preliminary processing, and preparation of milk quality parameters for classification.

Components:

- Sensors: pH sensor, TDS sensor, turbidity sensor, TCS34725 colour sensor, DS18B20 temperature sensor, and HX711 with a load cell for density measurement.
- Microcontroller: ESP32 DevKit V1 for sensor data acquisition and processing.
- Display: ST7735 TFT display for showing milk quality and adulteration detection results.
- User Interface: TTP223 touch sensor for user interaction and system control.

2. Data Processing and Machine Learning Module:

This module processes the collected sensor data through calibration and standardization using StandardScaler. The trained Support Vector Machine (SVM) model classifies the sample into Pure, Water-adulterated, Detergent-adulterated, or Starch-adulterated categories. If the prediction confidence is below 0.60, the system recommends retesting the sample.

3. Display and Monitoring Module:

This module presents the test results through an ST7735 TFT display and a Wi-Fi-enabled web dashboard. The TTP223 touch sensor supports user interaction, while the dashboard allows users to view the milk classification and related sensor information.

4. Automatic Cleaning Module:

This module uses a 6 V peristaltic pump to flush the testing chamber with distilled water for approximately five seconds after testing. The cleaning process helps remove residual milk and prepares the chamber for the next sample.

These modules work together to provide a portable and user-friendly system for preliminary milk adulteration detection using sensor measurements and Edge Machine Learning.

III. IMPLEMENTATION

The Aqua Milk Detect system is implemented by integrating sensor hardware, an ESP32 microcontroller, a Machine Learning model, and a web-based monitoring interface. The implementation is divided into hardware integration, software development, model deployment, and result visualization.

3.1 Hardware Implementation

The Aqua Milk Detect system uses an ESP32 DevKit V1 as the main controller along with multiple sensors and peripheral components.

Table 1: Hardware Components.

Component	Description
ESP32 DevKit V1	Main controller for sensing and processing.
pH Sensor	Measures milk pH.
TDS Sensor	Measures total dissolved solids.
Turbidity Sensor	Measures milk turbidity.
TCS34725 Sensor	Measures milk colour.

DS18B20 Sensor	Measures milk temperature.
HX711 + Load Cell	Measures weight for density calculation.
ST7735 TFT	Displays test results and readings.
TTP223 Touch Sensor	Provides touch-based control.
Peristaltic Pump	Flushes the test chamber.
IRF520 + 2N2222	Controls the pump.
LM2596 Buck Converter	Provides regulated power.

3.2 Software Implementation

The software technologies used for developing the Aqua Milk Detect system are shown in Table in Table 2.

Table 2: Software Tools & Techonologies.

Component	Description
ESP32 DevKit V1	Main controller for sensing and processing.
pH Sensor	Measures milk pH.
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TTP223 Touch Sensor	Provides touch-based control.
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LM2596 Buck Converter	Provides regulated power.

3.3 Machine Learning Model Deployment

A Support Vector Machine (SVM) classifier is trained using labelled sensor data to distinguish four classes: Pure, Water-adulterated, Detergent-adulterated, and Starch-adulterated. The model is developed in Python using scikit-learn, and micromlgen is used to generate code suitable for deployment on the ESP32.

The trained model and corresponding scaling parameters are integrated into the microcontroller firmware. This Edge Machine Learning approach enables local classification without requiring cloud-based inference. When the prediction confidence is below 0.60, the system displays "Uncertain – Retest" instead of presenting the result as a confident classification.

3.4 Result Display and Automatic Cleaning

After classification, the result is displayed on the ST7735 TFT screen and made available through the Wi-Fi web dashboard. The interface provides users with the classification outcome and associated sensor information.

Once the test is completed, the automatic cleaning mechanism operates a peristaltic pump to flush the testing chamber with distilled water for approximately five seconds. This helps remove residual sample material and prepares the system for subsequent testing.

IV. TESTING

The Aqua Milk Detect system is tested to verify the functionality of its sensors, data-processing pipeline, Machine Learning model, display interface, and automatic cleaning mechanism. Testing is performed to ensure that the integrated hardware and software operate as intended.

4.1 Sensor Testing

The pH, TDS, turbidity, colour, temperature, and density sensors are checked to verify that they collect milk sample measurements correctly. Sensor readings are monitored through the ESP32, and multiple readings are averaged over approximately three seconds to improve consistency. Calibration is performed to support reliable data collection.

4.2 Machine Learning Model Testing

The trained Support Vector Machine (SVM) model is tested using labelled sensor data representing four classes: Pure, Water-adulterated, Detergent-adulterated, and Starch-adulterated.

The processed sensor values are standardized using the retained StandardScaler parameters before classification. The predicted category is checked against the known sample label to assess classification performance.

4.3 System Integration Testing

The complete system is tested to verify communication between the sensors, ESP32, ST7735 TFT display, TTP223 touch sensor, and Wi-Fi web dashboard. The test checks whether sensor readings are processed and classification results are displayed correctly. When prediction confidence falls below 0.60, the system should display "Uncertain – Retest."

4.4 Automatic Cleaning Testing

The automatic cleaning mechanism is tested to verify the operation of the 6 V peristaltic pump. After a test, the pump flushes the testing chamber with distilled water for approximately five seconds. The cleaning process is checked to ensure that the mechanism operates as intended before the next sample is tested.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	timestamp	milk_type	adulterant	level_pct	source	temp_c	ph_raw_n	tds_raw_r	turbidity_r	color_r	color_g	color_b	color_clear
2	370380	toned	pure	0		18.65	404.7	2416.2	284	10	10	6	27
3	391941	toned	pure	0		18.72	502.2	2416.4	284	2	2	1	6
4	401929	toned	pure	0		18.75	513.7	2416.3	284	2	2	2	6
5	422035	toned	pure	0		18.98	519.3	2416	284	2	2	1	4
6	435289	toned	pure	0		18.86	551.8	2416.3	284	2	2	1	5
7	446040	toned	pure	0		18.81	573.9	2416.3	284	2	2	1	4
8	687759	toned	water	50		23.78	400	2316.9	284	2	2	1	6
9	700082	toned	water	50		24.53	452.9	2322.5	284	2	2	2	5
10	712062	toned	water	50		24.83	532.5	2323.7	284	2	2	1	5
11	720000	toned	water	50		24.88	538.9	2323.4	284	1	1	1	4
12	731685	toned	water	50		24.94	565.4	2320	284	2	2	1	5
13	740067	toned	water	50		24.94	611.3	2310.5	284	2	2	1	5
14	933478	toned	water	50		25.78	1668.6	2418	284	2	2	1	5
15	963391	toned	detergent	100		28.66	1885.3	2417.9	284	2	2	1	6

Fig.2. Sample labelled sensor dataset recorded during data collection



Fig.3. Test History

V. RESULTS AND DISCUSSION

The Aqua Milk Detect system integrates multiple sensors, an ESP32 microcontroller, and a Support Vector Machine (SVM) model to perform preliminary milk adulteration screening. The system is designed to collect milk parameters, process the sensor readings, classify the sample, and display the result through a TFT display and a Wi-Fi web dashboard. The hardware and software prototypes are shown in Fig. 4 and Fig. 5, and the evaluation parameters are summarized in Table III.

Hardware:

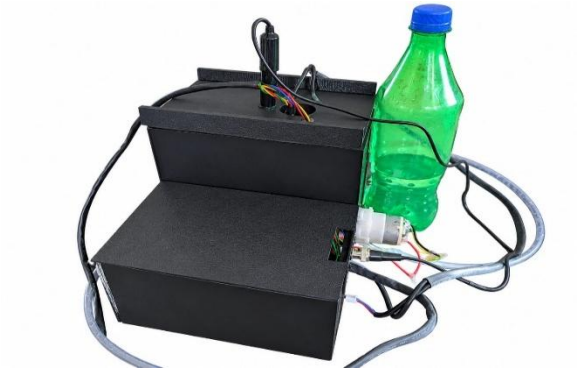

Fig. 4. Hardware Prototype

Software:

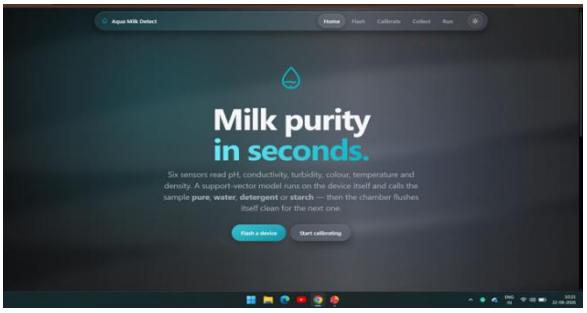

Fig.5. Software Prototype

Table 3: Performance Evaluation parameters

Evaluation Parameter	Experimental Result
Sensor reading time	Approximately 3 seconds
Milk classification categories	4
SVM classification accuracy	To be measured
Precision and recall	To be calculated
Low-confidence threshold	0.60
Automatic flushing duration	Approximately 5 seconds
Display and dashboard operation	To be verified experimentally



Fig. 1. Mobile dashboard: session test history



Fig. 2. Mobile dashboard live view: sample classified as Water (adulterated)



Fig. 3. Mobile dashboard live view: low-confidence result reported as Uncertain

Fig. 6 is the test history with verdicts and confidence, Fig. 7 is a live result classified as Water (adulterated), and Fig. 8 is a low-confidence result (52%, below the 0.60 threshold) reported as "Uncertain" with a retest advised.

VI. CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

Aqua Milk Detect is a low-cost and portable IoT-based system developed for preliminary milk adulteration screening using sensor technology and Edge Machine Learning. The system uses an ESP32 microcontroller integrated with pH, TDS, turbidity, colour, temperature, and density sensors to collect milk parameters. A Support Vector Machine (SVM) model classifies samples into four categories: Pure, Water-adulterated, Detergent-adulterated, and Starch-adulterated.

The system displays classification results through an ST7735 TFT display and a Wi-Fi web dashboard. A confidence threshold of 0.60 is used to identify low-confidence predictions, for which the system displays an “Uncertain – Retest” message. The automatic flushing mechanism uses a peristaltic pump and distilled water to prepare the testing chamber for subsequent samples.

Overall, Aqua Milk Detect combines sensor-based monitoring, local Machine Learning inference, and automated cleaning in a portable system. It offers a practical approach to preliminary milk adulteration screening. However, further experimental validation is required to establish its classification accuracy, reliability, and suitability for different milk samples.

6.2 Future Scope

The following improvements can be considered in future versions of Aqua Milk Detect:

1. Improved Classification Accuracy: Collect a larger and more diverse dataset and evaluate alternative Machine Learning algorithms to improve classification performance.
2. Expanded Adulterant Detection: Extend the system to identify additional adulterants and different levels of adulteration.
3. Enhanced Sensor Calibration: Improve sensor calibration and investigate methods to reduce measurement variations caused by temperature, sample composition, and sensor drift.

4. Advanced Monitoring Dashboard: Add historical test records, graphical analysis, and downloadable reports to improve data visualization and monitoring.
5. Extended Experimental Validation: Evaluate the system using laboratory-verified samples and compare its predictions with established testing methods.
6. Improved Portability and Automation: Optimize power consumption, enclosure design, and the automatic cleaning mechanism to make the device more convenient for repeated field testing.

These improvements could enhance the usability and reliability of Aqua Milk Detect and support its further development as an accessible preliminary milk quality screening system.

REFERENCES

[1] S. Shahzad, S. Javaid, and Z. Alamsyah, "Milk Quality Detection Using Machine Learning," *International Journal of Advanced Computer Science and Applications*, 2025.

[2] R. Mhapasekar, D. Kilbane *et al*., "A Systematic Review of IoT and AI Applications in Milk Quality Monitoring," *Journal of Food Quality and IoT Systems*, 2025.

[3] Bhattacharya and Das, "IoT-Based Milk Quality Monitoring System," in *Proc. International Conference on Smart IoT Applications*, 2022.

[4] "Arduino-Based Milk Adulteration Detection System," *International Journal of Engineering Research and Technology (IJERT)*, 2023.

[5] Researchers using Kaggle Milk Dataset, "Machine Learning Based Milk Quality Prediction," *International Journal of Machine Learning Research*, 2023.

[6] D. Lakshmi N., S. Priyanka S., M. Satya Sai Ram, and D. Bhasker, "Smart Milk Grading System for Quality Assessment and Adulteration Detection using IoT," International Journal of Innovative Technology and Research, 2024.

[7] M. G. Lanjewar, S. S. Sonavane, and P. S. Patil, "Machine Learning-Based Technique to Predict Water Adulteration in Milk Using NIR Spectroscopy," in Proc. IEEE Conference on Smart Agriculture and Food Safety, 2024.

[8] "AI-Powered Real-Time Milk Adulteration Detection and Quality Monitoring System," International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), 2025.

[9] Jain et al., "IoT and Arduino-Based Automated Milk Collection and Monitoring System," *International Journal of Emerging Technologies*, 2023.

[10] Bhade *et al*., "IoT-Based Milk Quality Analyzer using AVR Microcontroller," *International Journal of Scientific Research in Engineering and Management*, 2022.