Automated System for Identifying Contaminants in Milk and its Products

K. Ezhilarasan
Dept of Electronics and Communication Engg.
S J C Institute of Technology, Chickballapura
Karnataka, India

B. Sreevidya
Dept of Electronics and Communication Engg.
S J C Institute of Technology, Chickballapura
Karnataka, India

Bhavya S.A.
Dept of Electronics and Communication Engg.
S J C Institute of Technology, Chickballapura
Karnataka, India

Hamsa K.S.
Dept of Electronics and Communication Engg.
S J C Institute of Technology, Chickballapura
Karnataka, India

ABSTRACT
Milk consumption has increased constantly, with milk being part of the diet of a large proportion of the global population. As a result of this growing demand, the increased competition in the dairy market, and the increasing complexity of the supply chain, the producers in the sector of milk and dairy products resort to technological fraud, which is considered as predominant problem in various countries.[30] Therefore, further research is required to educate the public about fraud or carelessness in milk production. Over time, as counterfeiting methods have become more complex, detection techniques have had to be developed in the same sequence. This paper aims to review the main adulterants, detection techniques, and various methods of detecting defilements in milk.

Keywords
Milk adulteration, detection techniques, various sensors

1. INTRODUCTION
Milk is undoubtedly a ubiquitous food in the human diet. This is the first food of mammals and, as such, provides all the energy and nutrients needed for proper growth and development. Adulteration of milk and dairy products has become a worldwide concern; however, the history of milk counterfeiting is very old. In the old German Empire, milk was diluted, and then its consistency was restored by adding sugar, flour, or calcium carbonate [30]. Unfortunately, milk and dairy products are among the most counterfeited foods worldwide. The reasons behind this fraud are mainly the perishable nature of milk, the shortage of supply and demand to meet urban demand, and the lack of adequate detection methods. Although consumers have a right to believe that the milk they purchase will be pure and unadulterated, this is regrettably not always the case. Adulteration is normally carried out either for financial gain or because of a lack of proper hygiene during processing, storage, transport, and marketing. Eventually, it reaches the stage where the consumer is either deceived or becomes a victim of disease. Milk is produced throughout the year. However, heat stress during the summer months significantly lowers milk production.

The Internet of Things (IoT) allows for more intuitive and remotely diagnosed active communication. The use of IOT is advantageous because of its effectiveness in results with accuracy, financial ascendancy in reckoning to compact human being involvement. Milk is destructible, for this reason it is hard to manage it for a longer period of time.

The global consumption of milk and dairy products is rising steadily. Dairy products, in addition to milk, are significant sources of nutrition for people. Additionally, it gives dairy farmers, processors, store owners, and other participants in the dairy value chain a means of subsisting. Commercially available milks include dairy milk, plant-based milks, infant formula, etc. and currently, cow's milk is more frequently consumed than plant-based milks. India consumes about 77.68 million tons of milk annually.

2. LITERATURE SURVEY
N. Sowmya et. al [1], made a low-cost and portable multispectral spectroscopic sensor system which uses machine learning techniques to differentiate adulterants. Three different wavelength bands ranging from 410 nm to 940 nm were used in the prototype, to increase the accuracy of detection. The system provides real-time publication of results through a web interface. To solve the problem of detecting adulterants, the study formulated it as a classification issue and employed machine learning algorithms to solve it. An algorithm was used to fine-tune the neural network model, which achieved a 100 percent accuracy rate for the system.

Fanelli V et al. [2] have aimed to provide details on adulteration of milk. That is the different detection techniques and also the detailed information about the adulterants presents in it also the evaluation of adulterants commonly found in milk samples.

Avula, V et.al [3] Paper-based microfluidic techniques could be the potential alternative for addressing the disadvantages mentioned above in the context of adulterants detection in milk. It is reported that the paper-based microfluidic approaches have used to detect heavy metals, antibodies, sulfur dioxide, benzoic acid, D-glucose, formaldehyde, and other compounds in various liquid food samples based on colorimetric detection.

Yang, Y., Y. [4] et al created a paper-based device for detecting glucose and protein in samples. To give a proper direction to the flow, the authors coated the chromatography papers with hydrophobic agents (SU-8 2010), followed by the exposure to the UV light to make the channels hydrophilic. However, the photo-lithography technique adopted in their study is costly and complicated. Hence, researchers have developed more simpler methods for creating hydrophobic barriers.

Shrikrishna, N. S et.al [5] have shown that milk quality can be evaluated based on two main aspects. One approach is to measure the quality of milk based on its nutritional content, such as its fat, protein, and lactose levels. Another approach focuses on determining the presence of bacteria in milk, such as mastitis or bacterial contamination. Both aspects are important for ensuring the safety and quality of milk for consumption.

Dhoble et al. [6] implemented an electronic sensor-based system which was used to detect infections in raw and unprocessed milk. A pH sensor and infrared signal receiver and transmitter modules made up the electronic sensor system.

Singh, M et al. [7] Milk is one of the most consumed food products in India. And it is one of the utterly fine dairy products which have higher chances of getting destroyed by any corruption in milk. Milk is considered as the natural and pure product; nowadays it is hard to consider milk identical as pure and natural. Because the corruption in milk increased day by day such as the use of chemical constituents and decontaminants.

Shalileh, F. et.al [8] The previously proposed methods were fine for calculating adulteration in milk. The technology that is being proposed in this paper is using some factors to identify the corruption in milk. A study was performed to check the significance of numerous bacterial counts (CC, LPC, TAC and PIC), all indicating the hygiene factors for dairy farms and all these factors are further cross-checked with the earlier case study.

Bastan, N et.al [9]A narrative and important tools were developed for the inspection of contemplative organic constituents in the dairy products. The demonstration method works with the reaction based on DNA, and these DNA can be formed with the processing of dairy products, that was the initial screening tool which gives the advantage of quick inspection for the adulteration of milk.

Momtaz, Bubli et.al [10] To inspect the addition of water in the milk a model has been proposed already which is able to detect the amount of water being used in coarse milk. Because milk is a perishable product which is easy to destroy.

Yang, Y et.al [11] In many of the cases, consumers are often suspected with diseases only by consuming the corrupted milk. This may cause skin, eye, cancer or other heart diseases. [6] Sheep milk and goat milk is also found adulterated by mixing that with cow milk; this adulteration is found in a case study where the examination takes place with respect to yak milk where it contains 1-100 percent of cow milk which can be inspected with the help of heat treatment.

Shrikrishna, N. S.,[12] The addition of certain substances such as detergents, salt, and glucose to milk increases its thickness and viscosity, while starch prevents curdling. However, these adulterants can have negative health consequences, such as detergent causing food poisoning and gastrointestinal issues, and other additives leading to organ dysfunction, heart problems, cancer, and even death. These harmful effects highlight the importance of developing straightforward and efficient methods to monitor milk adulteration.

The work by D. Kourtiet.al [13] proposes an IoT system for milk adulteration detection with real-time monitoring. The system uses a pH sensor, color sensor, and viscosity sensor to monitor milk quality, the values are compared with a set threshold. The system does not use any machine learning model to predict the adulterants in milk but only detects if the milk has been adulterated based on a comparison with the set threshold values. The data is then stored in the cloud.

A. Sarkar et.al [14] proposed a system based on sensing and quantifying the adulterants in milk by using laser diffraction principles and processing this data with a multilayered perceptron (MLP) neural network, which could classify the two adulterants – urea and water. The authors used a Raspberry Pi for processing the data and suggested using non-linear regression models to quantify the adulterants.

Near Infrared Spectroscopy employed to detect the fraudulent added in the goat milk [15]. Cow's milk, whey, water and urea are mixed at various concentrations from 0 (control), 20, 15, 10,5 and 1 percent volume/Volume with the goat milk. The Partial Least Square Discriminant Analysis (PLS-DA) methods applied along with K- Nearest Neighbor (K-NN) algorithm achieves 100 percent of sensitivity in validation, prediction and calibration.

Mid Infrared Spectroscopic (MIR) analysis is proposed to identify the blending effect of adulterated milk powder [16]. The adulterants are mixed by wet blending and dry blending methods. Semi-carbazide, Ammonium Sulphate and corn starch are the adulterants mixed in the milk Powder samples.

The objectives of this project are to rapidly detect and identify contaminants (urea, water content.) in milk and its products. To minimize the risk of food illnesses by preventing contaminated milk from reaching consumers. To develop and implement algorithms that accurately classify contaminated milk samples. To replace slow, manual testing methods with automated, continuous monitoring systems.

3. PROBLEM STATEMENT

Traditional methods for detecting contaminants in milk rely on laboratory-based chemical and microbiological analyses, which are often time-consuming, costly, and require skilled personnel. These limitations hinder the ability to perform large-scale, real-time monitoring in dairy supply chains, leading to potential public health hazards and economic losses. Therefore, there is a critical need for an automated system capable of rapid, accurate, and cost-effective detection of contaminants in milk and its products.

4. PROPOSED METHODLOGY

The block diagram includes mainly 4 blocks and they are:

i. Milk and its products sample block

ii. Sensors block

iii. Arduino UNO

iv. Power supply

v. LCD block

The main advantages of the proposed system are, in smaller industries available space will be limited, so this digital device for the estimation of the constituents of milk can be used.

i) Milk and Milk Product Sample Block:

This block represents the collection and preparation of samples for testing. Milk and egg product samples are first collected in a clean, sterile container to avoid external contamination. These samples are then introduced to the sensor system, which detects specific contaminants such as bacteria, adulterants, or spoilage indicators. The quality of sample preparation is crucial to ensure accurate detection and reliable results

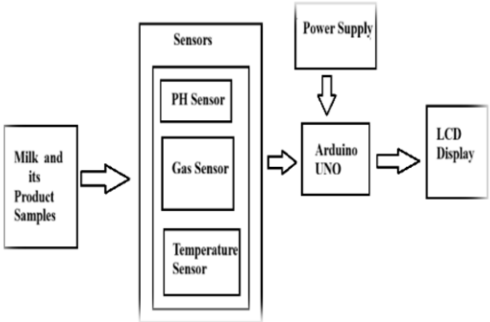

Fig3.1 Block Diagram of Proposed Methodology

ii)Sensor Block: This block includes-

(a)A pH sensor is a device that measures the hydrogen ion concentration (pH) of a solution, indicating how acidic or basic (alkaline) it is. The pH scale ranges from 0 (very acidic) to 14 (very basic), with 7 being neutral (e.g., pure water).

(b)A temperature sensor detects and measures the thermal energy (heat) of an object or environment and converts this into a readable signal (analog or digital). It's critical in processes where maintaining a specific temperature is vital — such as milk processing, storage, and transport.

(c)A gas sensor detects the presence and concentration of gases in an environment. In milk quality analysis, gas sensors are used to identify volatile compounds produced during spoilage.

iii)Arduino UNO:

The Arduino UNO acts as the central processing unit of the system. It receives electrical signals from the sensor block, processes the data, and determines whether contaminants are present above safe limits. The Arduino is programmed to Interpret sensor signals, Compare them with preset thresholds for safe consumption, Trigger outputs accordingly. This ensures that the system can operate in an automated and efficient manner, reducing the need for manual testing

iv)Power Supply Block:

A stable power supply is essential for consistent operation of the sensors, Arduino UNO, and the output display. This block ensures that the system components receive the required voltage and current, thereby maintaining accuracy and reliability throughout the detection process. Battery or DC power sources are commonly used to make the system portable and convenient for on-site testing.

v)LCD Display Block:

The LCD block serves as the user interface, displaying the results of the analysis in a clear and readable format. Once the Arduino processes the sensor data, the LCD shows whether the sample is safe or contaminated. Advanced systems may also provide quantitative readings of contaminant concentration, giving users detailed information about the quality of the milk or its product.

5. RESULT

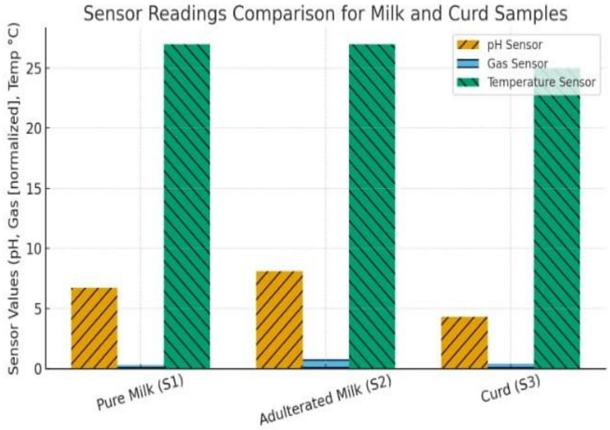

Fig4.1 Bar Graph w.r.t Sensor Readings

The bar graph illustrates the comparative readings of pH, gas, and temperature sensors for three samples — pure milk (S1), adulterated milk (S2), and curd (S3). Each sensor response helps in analysing the quality and purity of the samples.

i) pH Sensor: Pure milk shows a pH value of around 6.7, which lies within the normal fresh milk range.

Adulterated milk displays a higher pH of 8.1, indicating the presence of alkaline substances such as detergents or other impurities.

Curd records a low pH of 4.3 due to lactic acid formation during fermentation.

Observation: The pH level increases in adulterated samples and decreases in fermented products like curd, making it a key factor in purity detection.

ii) Gas Sensor: Pure milk shows a low gas value (0.3), confirming freshness and no chemical reactions.

Adulterated milk gives a high gas value (0.8), which may result from reactions between contaminants and natural milk compounds.

Curd has a moderate value (0.4), caused by natural fermentation gases.

Observation: The gas sensor effectively identifies chemical adulteration or spoilage based on abnormal gas emissions.

iii)Temperature Sensor: The temperature readings for pure and adulterated milk are nearly 27°C, while curd records 25°C.

These small variations indicate that temperature remains mostly constant and does not directly affect adulteration detection but helps maintain consistent test conditions.

Table1: Sample Sensor Readings for Pure Cow Milk

Parameter	Sensor Used	Sample Reading	Normal Range
PH Value	PH Sensor	6.7	6.6-6.8
Gas Concentration	MQ135	120ppm	<150
Temperature	DS18B20	27°C	25°C-30°C

Table2: Sample Sensor Readings for Adulterated Milk

Parameter	Sensor Used	Sample Reading	Normal Range
PH Value	PH Sensor	5.8	6.6-6.8
Gas Concentration	MQ135	230ppm	<150
Temperature	DS18B20	31°C	25°C - 30°C

Table3: Sample Sensor Readings for curd

Sensor Used	Sample Reading	Normal Range
PH Sensor	4.5	4.4-4.6
Gas Sensor	160ppm	<180ppm
Temperature Sensor	29 °C	25 °C-30 °C

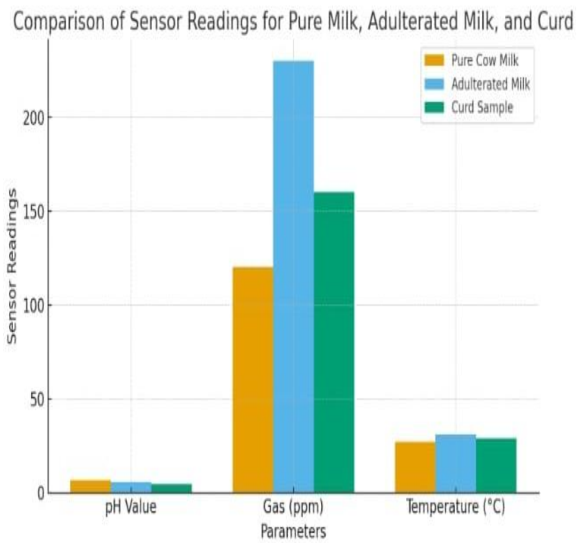

Fig 4.2 Bar Graph w.r.t Comparison of Sensor Readings

The bar graph compares pH, gas, and temperature readings of pure cow milk, adulterated milk, and curd. Pure milk shows normal values — pH 6.7, gas 120 ppm, and temperature 27°C, indicating freshness. Adulterated milk has a lower pH (5.8) and higher gas (230 ppm), showing contamination and spoilage. Curd naturally has a low pH (4.5) due to fermentation, with moderate gas (160 ppm) Sensor and temperature (29°C) within normal range.

6. CONCLUSION

As milk is consumed everywhere in the world, its adulteration represents a global concern. People are concerned about the quality and purity of milk due to the increasing fraudulent practice of adulterating milk. As a consequence, the consumers' health may be harmed by milk adulterants such as water, vegetable and animal fat, extraneous proteins, and chemical additives such as melamine, urea, ammonium sulphate, formalin, acids (e.g., boric acid, benzoic acid, salicylic acid), caustic soda, hydrogen peroxide, detergents, and sugars that are knowingly added. Various techniques have been developed over time to identify adulterants in milk, but the most accurate are instrumental. Therefore, there is an increasing need for the development of reliable, affordable, and non-expensive methods and technologies that could detect and stop the practices of adulteration. This review provides an understanding of the many types of additional adulterants as well as the most effective qualitative and quantitative approaches for their identification in order to preserve the nutritional character of milk.

7. FUTURE SCOPE

The future scope of the automated system for detecting contaminants in milk and its products is quite promising, especially with the growing need for safe and high-quality dairy. The system can be enhanced by integrating IoT and cloud technology for real-time monitoring, enabling instant detection of contamination at farms, processing units, or retail outlets. Adding AI and machine learning can improve accuracy in detecting contaminants, predict trends, and identify potential issues before they become serious. The system can also be extended to test various dairy products like cheese, yogurt, and butter, ensuring quality across the supply chain.

8. REFERENCES

[1] N. Sowmya, V. Ponnusamy, "Development of spectroscopic sensor system for an IoT application of adulteration identification on milk using machine learning," IEEE Access, 9, pp. 53979-53995, Apr. 2021.

[2] Fanelli V; Mascio, I Miazzi M.M.; Savoia, M.A.; De Giovanni, C.; Montemurro, C. Molecular Approaches to Agri-Food Traceability and Authentication: An Updated Review. Foods 2021, 10, 1644.

[3] Fu, X.; Wu, J.; Xu, H.; Wan, P.; Fu, H.; Mei, Q. Luminescence nanoprobe in the near-infrared-II window for ultrasensitive detection of hypochlorite. Anal. Chem. 2021, 93, 15696–15702.

[4] Mafra, I.; Honrado, M.; Amaral, J.S. Animal Species Authentication in Dairy Products. Foods 2022, 11, 1124.

[5] Avula, V.; Sundar, S.P.; Sree Rekha, B.; Kalpana, M. Analytical methods to detect the Adulterants in Milk—An Overview. Asian J. Res. Pharm. Sci. 2022, 12, 272–276.

[6] Singh, M. Nano sensor Platforms for Detection of Milk Adulterants. Sens. Actuators Rep. 2023, 5, 100159.

[7] Shalileh, F.; Sabahi, H.; Dadmehr, M.; Hosseini, M. Sensing approaches toward detection of urea adulteration in milk. Microchemist. J. 2023, 193, 108990.

[8] Bastan, N.; Ahmadi, M.; Madrakian, T.; Afkhami, A.; Khalili, S.; Majidi, Moradi, M. A paired emitter–detector diode-based photometer for the determination of sodium hypochlorite adulteration in milk. Sci. Rep. 2023, 13, 6217.

[9] Momtaz, M.; Bubli, S.Y.; Khan, M.S. Mechanisms and Health Aspects of Food Adulteration: A Comprehensive Review. Foods 2023, 12, 199

[10] [10] Yang, Y., Y. Du, V. K. Gupta, F. Ahmad, H. Amiri, J. Pan, M. Aghdashloo, M. Tabatabaei, and A. Rajaei. 2024. Exploring blockchain and artificial intelligence in intelligent packaging to combat food fraud: A comprehensive review. Food Package. Shelf Life 43:101287. https:// doi.org/10.1016/j.fpsl.2024.101287.

[11] Shrikrishna, N. S., R. Sharma, J. Sahoo, A. Kaushik, and

S. Gandhi. 2024. Navigating the landscape of optical biosensors. Chem. Eng. J. 490:151661. https://doi.org/10.1016/j.cej.2024.151661.

[12] D. Kourti, M. Angelopoulou, K. Misiakos, E. Makarona, A. Economou, P. Petrou, and S. Kakabakos, "Detection of adulteration of milk from other species with cow milk through an immersible photonic immunosensor," Eng. Proc., vol. 35, p. 582, 2023.

[13] A. Sarkar and A. Dutta, "The Milk Producers' Organization and Indian dairy sector—a strategic alignment," Veterinarska stanica, vol. 53, no. 3, pp. 329–342, 2022.

[14] P. P. Lal, A. A. Prakash, A. A. Chand, K. A. Prasad, U. Mehta, M. H. Assaf, F. S. Mani, and K. A. Mamun," IoT integrated fuzzy classification analysis for detecting adulterants in cow milk," Sensing and Bio-Sensing Res., vol. 36, 2022.

[15] S. Goswami and A. Dangi," Arduino based milk quality monitoring system," Int. J. Agric. Environ. Biotechnology., 2021.

[16] A. Tapadar, F. A. Khanday, S. Sen, and A. Adhikary, "Fractional calculus in electronic circuits: a review," in Fractional Order Systems, vol. 1, Academic Press, 2022, pp. 441–482.

[17] S. A. Mehdizadeh and M. Noshad," Smartphone application assisted optoelectronic nose for monitoring milk freshness," J. Food Eng., vol. 368, p. 111915,2024, Doi: 10.1016/j.jfoodeng.2023.111915.

[18] Y. K. Anagaw et al.," Food adulteration: Causes, risks, and detection techniques," SAGE Open Med., vol. 12, p. 20503121241250184,2024, Doi:10.1177/20503121241250184.

[19] M. Aqeel, A. Sohaib, M. Iqbal, H. U. Rehman, and F. Rustam, "Hyperspectral identification of oil adulteration using machine learning techniques," Curr. Res. Food Sci., vol. 8, p.100773,2024, Doi: 10.1016/j.crfs.2024.100773.

[20] S. Dortez, A. G. Crevillen, A. Escarpa, and S. Cinti," Electroanalytical paper-based device for reliable detection and quantification of sugars in milk," Sens. Actuators B Chem., vol. 398, p. 134704, 2024, Doi: 10.1016/j.snb.2023.134704.

[21] J. S. Farah et al.," Differential scanning calorimetry coupled with machine learning technique: An effective approach to determine the milk authenticity," Food Control, vol. 121, p.107585,2021,

[22] A. Roy, T. Rana, and A. Shee," Prevention and control of milk contamination, adulterants, antimicrobial residues, and agrochemicals," in The Microbiology, Pathogenesis and Zoonosis of Milk Borne Diseases, Elsevier, 2024, pp. 135–151, Doi: 10.1016/B978-0-443-13805-8.00012-0.

[23] U. Salmaz, A. N. Siddiquee, and T. Islam," A novel inexpensive capacitive sensor for instant milk adulteration detection," IEEE Trans. Instrum. Meas., vol. 73, p. 7501708, 2024, doi: 10.1109/TIM.2024.3353277.

[24] F. Sayyad, K. Gandhi, R. Sharma, T. M. Amrutha, P. B. Gautam, and C. G. Harshitha," Development and validation of paper-based strip method for the detection of formalin in milk," J. Food Sci. Technol., vol. 61, pp. 2367–2376, 2024, doi: 10.1007/s13197-024-06003-2.

[25] [25] G. Kaur, R. Bhari, and K. Kumar," Nano biosensors and their role in detection of adulterants and contaminants in food products," Crit. Rev. Biotechnol., vol. 44, pp. 547–561, 2024, doi: 10.1080/07388551.2023.2175196.

[26] A. Khan, M. T. Munir, W. Yu, and B. Young," Wavelength selection for rapid identification of different particle size fractions of milk powder using hyperspectral imaging," Sensors (Basel), vol. 20, p. 4645, 2020, doi: 10.3390/s20164645.

[27] S. Patari and P. S. Mahapatra," Imbibition of liquids through a paper substrate in a controlled environment," Langmuir, vol. 38, pp. 4736–4746, 2022.

[28] X. Han, K. Liu, S. Zhang, P. Peng, C. Fu, L. Qiao, and Z. Ma, "CSRR metamaterial microwave sensor for measuring dielectric constants of solids and liquids," IEEE Sensors Journal, vol. 24, no. 9, pp. 14167–14176, 2024.

[29] S. Kapse, P. Kedia, A. Kumar, S. Kausley, P. Pal, and B. Rai, "A noninvasive method for detection of freshness of packaged milk," Journal of Food Engineering, vol. 346, p. 111424, 2023.

[30] M Priya, S Namratha, M Bhuvaneshwari, Asha kagawad, K Ezhilarasan "Detection of Defilement in milk and its products", https://doi.org/10.1016/j.gltp.2021.08.015.