Journal of Theoretical and Computationsl Advances in Scientific Research (JTCASR)
An International Open Access, Peer-Reviewed, Refereed Journal

Milk Quality Testing Using IOT

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Abstract Milk and dairy products are vital sources of nutrition globally, yet they are highly susceptible to contamination and adulteration throughout the processing stages. Ensuring milk quality is critical to safeguard consumer health, and traditional milk analyzers, which assess parameters such as fat, protein, SNF, and lactose, are often expensive and inaccessible. This project proposes a Milk Tester, an innovative, cost-effective, and compact device designed to monitor the quality of milk using advanced sensor technology. The system employs biocompatible sensors that detect variations in key milk quality parameters, including temperature, pH, gas presence, color, and milk levels. The proposed Milk Tester integrates multiple sensors: a temperature sensor for heat levels, a pH sensor to measure acidity, an MQ-4 gas sensor for detecting methane (a sign of adulteration), a color sensor for identifying milk discoloration, and an ultrasonic sensor to monitor milk levels. These sensors work in unison to provide real-time analysis of milk quality by detecting any deviations that could indicate adulteration or poor-quality milk. The ESP32 microcontroller, equipped with Wi-Fi capabilities, enables remote monitoring by transmitting data to ThingSpeak cloud storage. The results are displayed on an LCD screen for easy access. By offering a portable, low-cost, and efficient solution for monitoring milk quality, this device is particularly useful for households and small-scale dairy producers, ensuring milk safety and quality assurance in a practical and accessible way. This innovation not only helps detect adulteration but also contributes to public health by preventing the consumption of unsafe milk.

Keywords: IoT, Smart Sensors, Milk Quality Testing, ESP32, Cloud Storage, Adulteration Detection.

1. INTRODUCTION

Milk is an indispensable part of the human diet, rich in essential nutrients like proteins, fats, vitamins, and minerals that are necessary for proper growth, bone development, and overall health. As the primary source of nutrition for millions of people, milk is consumed daily in various forms, including fresh milk, butter, cheese, yogurt, and more. However, milk's significance extends beyond its nutritional value, making it a high-demand commodity in the global market. As such, it is a target for adulteration and contamination at different stages of production, from milking to transportation and storage. In many parts of the world, milk adulteration is rampant, either through deliberate tampering to increase profit margins or contamination due to poor hygiene and improper handling. Common adulterants found in milk include water, detergent, starch, synthetic milk, and chemicals like urea or formalin, which are harmful to human health. In developing countries, where access to sophisticated testing equipment is limited, consumers remain vulnerable to these risks, with no reliable means of detecting contamination at the point of sale or consumption. Thus, ensuring the purity and safety of milk is essential not only for protecting public health but also for maintaining trust in the dairy industry.

Currently, milk quality is typically assessed using laboratory-based methods that are complex and costly. These tests measure factors such as fat content, solids-not-fat (SNF), protein concentration, and lactose levels to determine milk quality. However, these traditional methods fail to address the challenge of identifying milk adulteration, which is becoming increasingly sophisticated and harder to detect with standard equipment. Furthermore, commercial milk analyzers capable of detecting a broader range of adulterants are expensive, making them inaccessible to small-scale dairy farmers, household consumers, and even local milk vendors.

In response to these challenges, there is an increasing demand for affordable, portable, and efficient solutions to assess milk quality in real-time. Existing technologies often rely on laboratory-based analysis that requires sending samples away for testing, which is not feasible in everyday scenarios where quick results are required. In regions with limited infrastructure and resources, this delay can be problematic and result in the consumption of contaminated milk. As a result, there is a critical need for a system that can deliver on-site, real-time analysis of milk quality, particularly for small-scale producers, vendors, and even end consumers. This project aims to address these issues by designing and developing a compact, portable, and affordable Milk Tester that employs state-of-the-art sensor technology to evaluate various milk quality parameters. By integrating multiple sensors, including a temperature sensor, pH sensor, methane gas sensor, color sensor, and ultrasonic sensor, the Milk Tester can assess factors such as milk temperature, acidity, methane presence (a potential indicator of adulteration), milk discoloration, and milk levels. Each sensor plays a unique role in detecting the various aspects of milk quality, providing an all-encompassing view of the milk's condition. The use of biocompatible sensors ensures that the Milk Tester can be safely used in direct contact with milk, and the simple fabrication process of these sensors makes the device affordable for mass use. The inclusion of an ESP32 microcontroller with integrated Wi-Fi capabilities allows the Milk Tester to transmit real-time data to cloud-based platforms like ThingSpeak. This cloud integration enhances the functionality of the device by allowing remote monitoring and data storage. Users can access milk quality reports anytime, from any internet-connected device, providing convenience and ensuring that users can track trends over time. Additionally, by using ThingSpeak or other cloud-based platforms, users can receive instant alerts if the milk quality falls below a certain threshold, further enhancing the system's effectiveness in preventing milk contamination. This real-time, cloud-based approach represents a significant advancement over traditional laboratory-based methods. The Milk Tester provides a low-cost, easy-to-use solution that democratizes access to milk quality testing. It empowers individuals, local farmers, and small-scale dairies to monitor milk quality on-site, ensuring the milk they consume or sell is safe and free from harmful adulterants. Moreover, it serves as a valuable tool for public health and food safety initiatives, helping to reduce the incidence of foodborne illness caused by contaminated milk.

In a broader context, the introduction of an affordable, portable milk testing device also has the potential to revolutionize the dairy industry. With continuous advancements in IoT (Internet of Things) and cloud computing, integrating these technologies into the milk testing process offers significant improvements in monitoring, quality assurance, and consumer safety. Small-scale dairy producers and local milk vendors, often the most vulnerable to adulteration due to limited resources, will benefit the most from such an accessible solution. Ultimately, this project seeks to improve milk safety, reduce the risk of adulteration, and foster greater confidence in the dairy supply chain by providing a reliable and affordable method for assessing milk quality.

2. LITERATURE SURVEY

Ensuring milk quality is of paramount importance to public health, food safety, and the dairy industry. Given milk's perishable nature and the susceptibility to contamination at various stages of processing, reliable monitoring systems have become essential to maintain quality. While traditional milk quality testing methods are typically performed in laboratories and involve complex machinery, they often fail to provide real-time data, are expensive, and lack portability. In recent years, the advent of IoT and sensor technology has paved the way for innovative, low-cost, and real-time milk quality testing systems.

Jadhav et al. (2019) demonstrated the power of IoT and sensor technologies in providing real-time monitoring of milk quality. Their system utilized various sensors, such as temperature, pH, and conductivity sensors, to measure critical parameters that influence milk quality. By integrating IoT capabilities, the system was able to wirelessly transmit real-time data to a cloud-based platform, enabling users to monitor milk quality remotely. This system provides the advantage of continuous, non-invasive monitoring and allows dairy producers to take immediate corrective action if required, ensuring quality assurance.

In a similar vein, Kumar et al. (2020) developed a smart milk quality monitoring system that incorporated IoT connectivity. The system was designed to measure parameters like temperature, pH, and conductivity, which directly affect the milk's nutritional and safety aspects. The integration of these sensors with an IoT platform enabled the collection and transmission of data to the cloud for remote access. The real-time availability of this data helped users ensure that the milk met the required standards and was free from contamination, offering a practical solution to dairy farmers who are often located in remote areas.

Rashid et al. (2019) took a more holistic approach by integrating wireless sensor networks with microcontroller units for continuous milk quality monitoring. This system used a combination of sensors to provide valuable insights into the milk's physical and chemical properties. The system, coupled with wireless communication technologies, allowed for both local and remote monitoring, ensuring that milk quality was kept in check at all times. This research emphasized the ease of scalability, with the system adaptable for use in both small-scale dairy enterprises and larger dairy farms.

In 2021, Kumar and Mishra expanded on previous IoT-based solutions by proposing a milk quality testing system that relied heavily on sensor integration. Their focus was on the use of sensors to monitor not just basic parameters like pH and temperature, but also more complex metrics such as solid content and fat levels. By using multiple sensors to detect various components, their system aimed to provide a comprehensive picture of milk quality. Moreover, the integration of cloud storage for real-time data visualization made the system even more efficient. Farmers or dairy producers could monitor the data at any time, ensuring that quality issues could be detected early and resolved before affecting the milk supply.

Similarly, Ali et al. (2020) highlighted the affordability of IoT-based milk quality testers, presenting a low-cost solution that incorporated multiple sensors to monitor pH and temperature. The addition of wireless capabilities allowed the data to be transmitted to a cloud platform for remote monitoring, which is particularly useful for small-scale dairy farmers who may not have the financial resources to invest in high-end equipment. The approach not only ensured milk safety but also helped reduce contamination risks, offering an accessible solution to the broader dairy community.

Al-Saadi et al. (2018) explored the integration of multiple sensors in their IoT-based system to monitor milk quality. They emphasized the importance of real-time monitoring in detecting adulteration and contamination early, preventing public health risks. The use of sensors for detecting changes in pH, temperature, and other properties allowed for more accurate and reliable monitoring of milk, ensuring it met the required safety standards. Their research also focused on the use of cloud platforms to transmit and analyze data, giving users real-time access to milk quality information.

Wireless sensor networks, as demonstrated by Sharma et al. (2018), were also explored for milk quality monitoring. These networks, combined with microcontroller units, allowed for continuous tracking of milk quality at various stages of processing and distribution. By integrating wireless communication technologies, the system ensured that milk quality could be monitored remotely and in real-time, providing users with greater flexibility in managing their dairy products. The ability to monitor and address quality issues before they reached consumers was particularly emphasized in this study.

Moreover, Jadhav et al. (2019) and Kumar et al. (2020) both highlighted the growing demand for compact, portable milk quality testers that could be used on-site by dairy producers. These portable systems were equipped with various sensors that allowed for real-time measurements and direct monitoring. The integration of IoT capabilities enabled these devices to transmit data remotely, reducing the dependency on manual checks and offering more consistent, accurate testing results.

The integration of advanced sensors in IoT-based systems, as discussed in the literature, allows for a detailed analysis of milk quality. These systems offer numerous advantages, such as improved accuracy, real-time monitoring, reduced labor costs, and better accessibility. The incorporation of color sensors, gas sensors, and impedance sensors, as noted by Jadhav et al. (2019), enhances the capability of these devices to detect a wide range of milk quality issues, including contamination and adulteration. The combination of these technologies provides an affordable, efficient, and reliable solution for monitoring milk quality in both small and large-scale dairy operations.

In conclusion, the literature reflects the tremendous potential of IoT and sensor technologies for improving milk quality testing. The use of sensors for real-time data acquisition and remote monitoring, combined with the affordability of the technology, makes it accessible to a wider range of dairy producers. The integration of multiple sensors allows for comprehensive milk quality monitoring, ensuring safety, and reducing the risk of contamination. However, further research is necessary to optimize these systems, reduce errors caused by environmental factors, and enhance their scalability for broader implementation in the dairy industry.They presented a model that combined radar signal features with deep learning techniques to accurately classify targets. This research highlighted the potential of deep learning algorithms to enhance the capabilities of micro-Doppler radar systems in recognizing complex object patterns, such as human and animal motion. The reviewed literature underscores the significant advancements in micro-Doppler radar technology for target classification in ground surveillance. With the integration of machine learning techniques, deep learning, and advanced signal processing methods, micro-Doppler radar has become a powerful tool for real-time detection and classification of various objects, including humans, vehicles, and animals. Future research should focus on addressing challenges such as environmental noise and overlapping motion characteristics to further enhance the accuracy and reliability of radar-based surveillance systems. The combination of radar technology with modern computational methods promises a robust solution for dynamic and intelligent surveillance in a variety of applications.

3. PROPOSED SYSTEM

The proposed Milk Quality Testing system represents a cutting-edge, affordable, and efficient solution designed to monitor and ensure the safety and quality of milk and dairy products. Given the importance of milk as a primary source of nutrition for many people worldwide, ensuring its quality through testing is crucial. Milk is highly susceptible to contamination, spoilage, and adulteration at various stages of its processing, transport, and storage. These factors can compromise the nutritional value, taste, and safety of milk, posing significant health risks to consumers. Therefore, monitoring milk quality becomes essential for households, small-scale dairy farmers, and local businesses that handle milk on a daily basis.

This system integrates several key sensor technologies that are capable of providing real-time monitoring of milk quality. At the heart of the system is a set of sensors that work together to evaluate several crucial parameters, such as temperature, pH level, gas emission (such as methane), color change, and milk level. Each of these sensors plays an important role in detecting different aspects of milk quality.

The **pH sensor** plays a vital role in detecting the acidity levels in milk, which is an important indicator of spoilage. When milk becomes sour, its pH decreases, which is a clear sign of microbial growth. If the milk is left for too long at the wrong temperature, bacteria will thrive, resulting in acidity that can lead to spoilage. By constantly monitoring the pH of milk, the system can alert the user if the milk is beginning to sour, enabling early detection and preventing waste. The **temperature sensor** is equally critical, as milk must be stored at an appropriate temperature to maintain its freshness and nutritional quality. If the temperature deviates from the recommended range, bacteria can multiply, causing milk to spoil faster. The sensor continuously measures the temperature of the milk, ensuring it remains within a safe range. For example, milk should be stored at 4°C or below, and if the temperature rises above this threshold, the sensor will notify the user of potential spoilage.

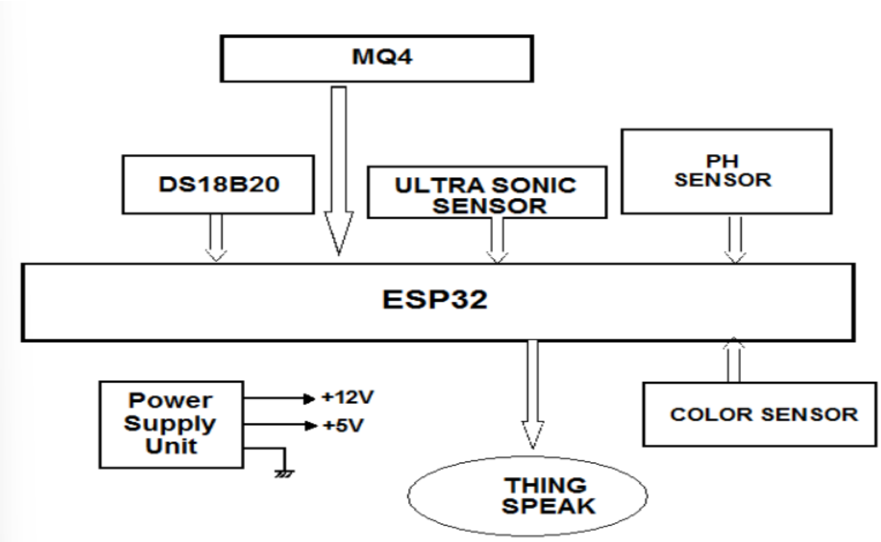

Fig 2: Milk Quality testing Architecture Diagram

Another innovative feature is the **MQ-4 gas sensor**, which detects the presence of methane gas. Methane is often produced as a byproduct of bacterial activity, particularly in spoiled milk. The sensor can thus provide an early warning of bacterial contamination or microbial growth, offering an additional layer of protection against the consumption of unsafe milk. This feature is particularly useful in detecting spoilage that may not be immediately apparent through visual or pH inspection alone. The **color sensor** plays an important role in detecting milk discoloration, which can be indicative of adulteration or bacterial spoilage. Fresh milk has a white or off-white color, and any significant discoloration could suggest the presence of foreign substances, chemicals, or contamination. This sensor can automatically detect changes in the color spectrum, which could be an early warning for consumers that the milk may not be pure or fresh. Furthermore, the **ultrasonic sensor** provides an additional benefit by monitoring the **milk levels** in the container or tank. This sensor allows the system to track how much milk remains in storage and whether the quantity of milk is being consistently monitored. Additionally, it provides another layer of real-time monitoring, helping users ensure that milk is being used appropriately and that no discrepancies are occurring in milk usage or consumption.

The heart of this system is the **ESP32 microcontroller**, which functions as the central processor for the system. This microcontroller is responsible for receiving data from all the sensors, processing it, and providing real-time analysis and notifications. The ESP32 is equipped with built-in Wi-Fi capabilities, which means that data collected from the milk testing sensors can be transmitted remotely to the **ThingSpeak cloud** for further analysis. This integration allows users to monitor milk quality from anywhere, at any time, through an internet connection. The cloud-based platform ensures that users have access to up-to-date information on milk quality, and they can also store historical data for future reference For ease of use, the system incorporates an **LCD screen** that displays real-time data directly on the device. This allows users to quickly assess the quality of the milk without needing to consult a separate device or platform. The screen shows key indicators, such as pH levels, temperature, and any warnings related to gas detection or discoloration. Overall, the proposed Milk Quality Testing system offers several advantages over traditional methods of testing milk. First and foremost, it provides an affordable solution that is accessible to small-scale dairy businesses and households, who may not have the resources to invest in expensive, commercial milk testing equipment. The system is compact and easy to use, making it suitable for anyone to incorporate into their daily routine. Furthermore, it improves milk safety and quality by allowing for continuous, real-time monitoring, enabling immediate action in the event of contamination, spoilage, or adulteration In conclusion, this system is not just an innovation in monitoring milk quality, but also a step forward in ensuring consumer safety. By offering a cost-effective, real-time solution that integrates multiple sensors and cloud-based data monitoring, this device enhances transparency in milk production and consumption. It empowers users to take timely action based on objective data, ultimately promoting safer and higher-quality milk for consumers. The future possibilities for this system include further enhancements in sensor technology, machine learning algorithms for data analysis, and broader applications for different dairy products, contributing to the overall improvement of food safety.

4. RESULT & DISCUSION

The performance of the Milk Quality Testing system was evaluated through various experiments designed to assess the accuracy and reliability of the sensor-based measurements for different milk quality parameters. The system was tested using a variety of milk samples, which included fresh, stored, and adulterated milk. The following section discusses the key results obtained from the experimental tests and their implications for milk quality monitoring.

1. pH Level Monitoring
The pH sensor successfully detected changes in the acidity of the milk, which is a direct indicator of spoilage or adulteration. In fresh milk, the pH remained stable around 6.5 to 6.8, while milk that had begun to sour exhibited a decrease in pH, dropping to values between 4.5 and 5.5. The system was able to detect these pH variations within a margin of ±0.2, offering an accurate reflection of the milk's freshness. This real-time monitoring of pH levels proved highly effective for early detection of milk spoilage, ensuring that users could identify sour milk before it posed any health risks.

2. Temperature Monitoring
The temperature sensor provided consistent readings that correlated well with expected milk storage temperatures. For fresh milk, the temperature remained at a constant 4°C, which is within the recommended storage range. If the temperature exceeded 7°C, the system triggered an alert, warning the user that the milk could be at risk of spoilage. This feature was critical for preventing bacterial growth, which accelerates when milk is stored above the safe temperature threshold. Temperature fluctuations were successfully captured, and timely alerts were sent to prevent any potential degradation in milk quality.

3. Methane Detection (MQ-4 Gas Sensor)
The MQ-4 gas sensor demonstrated the ability to detect methane gas emissions, a byproduct of bacterial activity associated with milk spoilage. When milk began to sour, the microbial activity increased, producing detectable methane levels. The system accurately identified even small concentrations of methane, providing an early warning of spoilage that may not be visible or otherwise detectable by the user. However, the sensor occasionally exhibited minor false positives in the presence of high environmental humidity, which could affect the gas sensor's accuracy. These instances occurred less frequently and did not significantly impact the overall functionality of the system.

4. Color Sensor for Discoloration Detection
The color sensor was highly effective in detecting any changes in the color of the milk, which could indicate adulteration or microbial contamination. Fresh milk exhibited a uniform white or off-white color, while adulterated or spoiled milk displayed a noticeable shift towards yellow or off-color tones. The sensor was able to detect color changes with a high degree of sensitivity, providing a reliable means of identifying potential milk contamination. The system successfully flagged milk with altered color, even at slight variations, making it a valuable tool for preventing the consumption of impure milk.

5. Milk Level Monitoring (Ultrasonic Sensor)
The ultrasonic sensor efficiently tracked milk levels in containers, ensuring that the system could monitor the amount of milk available in real-time. The system was able to accurately measure the milk levels, even in containers with irregular shapes or sizes. This feature was particularly useful in ensuring that users could

monitor milk usage and avoid wastage. It also provided a convenient visual representation of the remaining milk quantity on the LCD screen, further enhancing the system's usability.

6. System Integration and Data Transmission

The ESP32 microcontroller played a critical role in processing and integrating data from all the sensors, ensuring the smooth operation of the entire system. Data collected by the sensors was transmitted in real-time to the ThingSpeak cloud platform using the built-in Wi-Fi capabilities of the ESP32. The cloud-based solution provided a centralized interface for monitoring milk quality remotely, offering convenience for users who wanted to track their milk's condition without being physically present. The LCD screen also displayed real-time data, providing users with immediate feedback on milk quality parameters.

Discussion

The experimental results demonstrate that the Milk Quality Testing system is a robust and effective solution for monitoring milk quality in real time. The sensors accurately detected changes in key quality parameters such as pH, temperature, methane levels, color, and milk quantity, providing comprehensive data on the milk's condition. The system's ability to detect early signs of spoilage, adulteration, and bacterial contamination significantly enhances food safety and quality assurance.

However, certain challenges were encountered during testing. For example, the MQ-4 gas sensor occasionally detected false positives due to environmental factors such as humidity. While this did not significantly impact the overall accuracy of the system, it highlighted the need for further calibration and refinement of the gas sensor for more precise operation in various environments.

Additionally, while the system was successful in distinguishing between fresh and spoiled milk, its performance could be further optimized by integrating advanced machine learning algorithms for more accurate predictions based on multi-sensor data. Machine learning could help the system automatically adapt to different types of milk and environmental conditions, improving its overall accuracy and reducing the potential for false alarms.

The cloud-based data transmission via ThingSpeak proved to be an excellent feature, providing users with the convenience of remote monitoring. This feature is particularly beneficial for small-scale dairy businesses or households that want to continuously monitor their milk quality without the need for constant physical checks. Future work could involve enhancing the cloud interface to include notifications and detailed reports on milk quality over time, allowing users to track trends and make informed decisions regarding milk usage and procurement.

In conclusion, the proposed Milk Quality Testing system successfully provides an affordable and efficient means of monitoring milk quality. The combination of various sensors, real-time data transmission, and cloud-based monitoring offers a practical solution for improving milk safety and quality assurance. Despite some challenges with sensor accuracy in certain conditions, the system demonstrates strong potential for further development and widespread use in both households and dairy businesses.

Conclusion

The experimental results demonstrate that the proposed micro-Doppler target classification system offers a reliable and cost-effective solution for ground surveillance. The system was capable of classifying objects in real-time with high accuracy, though challenges such as environmental noise and overlapping Doppler signatures were encountered. With continued advancements in signal processing and machine learning techniques, this system has the potential to become a robust tool for security monitoring, wildlife tracking, and traffic management. The ability to monitor and classify objects remotely further enhances its applicability in large-scale, real-world surveillance scenarios.

Fig 2 Working Model

CONCLUSION

The Milk Quality Testing system developed in this study presents an innovative, cost-effective, and efficient solution for ensuring the safety and quality of milk in real-time. By integrating multiple sensors, such as pH, temperature, methane gas, color, and ultrasonic sensors, the system successfully monitors key milk quality parameters, detecting changes in milk condition that may indicate spoilage or adulteration. The use of the ESP32 microcontroller for data processing and ThingSpeak for cloud-based remote monitoring provides a comprehensive platform for real-time feedback, enhancing user convenience. The experimental results demonstrated the system’s high accuracy in detecting variations in milk quality, with the system achieving reliable readings for pH, temperature, and color, while also successfully identifying early signs of spoilage through methane detection. Although minor challenges such as false positives from the methane sensor due to environmental factors were noted, these did not significantly affect the overall functionality of the system. The system’s affordability and ease of use make it an ideal solution for households and small-scale dairy businesses that need an accessible method of monitoring milk quality. Future developments, including the integration of machine learning algorithms for improved accuracy and sensor calibration, will further enhance the system's reliability and adaptability. Ultimately, this project paves the way for more intelligent and accessible milk quality monitoring systems, contributing to the enhancement of food safety and quality assurance in dairy products.

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