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DEVELOPMENT OF AN ARDUINO-BASED PROTOTYPE FOR REAL-TIME MONITORING AND EARLY DETECTION OF PASTEURIZED MILK SPOILAGE

Athiena Peralta Dela Cruz[1], Phoebe De Leon Agdeppa[1], Misha Rica Enriquez Dela Cruz[1],
Isha Janine Ramirez Palaroan[1] Maria Eliza Bello[2], Mylene Masangya[2]

[1]*Student, Senior High Student, Colegio de San Juan de Letran-Manila*
[2]*Faculty Member, Colegio de San Juan de Letran-Manila*
Corresponding author. Email: athiena.delacruz@letran.edu.ph

ABSTRACT

Milk spoils easily due to changes caused by bacteria, making early detection important for safety and for reducing waste. This study developed an Arduino-based prototype that monitors pasteurized milk in real time using a pH sensor and a temperature sensor. The system was tested on five milk samples with different storage conditions over a 48-hour period. Calibration results showed that the pH sensor produced stable and accurate readings. During testing, pH levels dropped as spoilage increased, while temperature helped show how storage conditions affected the speed of spoilage. The prototype correctly identified fresh, spoiling, and spoiled samples in most trials, reaching an accuracy of 92%. These findings show that the device can serve as a low-cost and practical tool for everyday use. It offers a simple way to check milk quality, promote food safety, and prevent unnecessary waste at home or in small stores.

Keywords: *milk spoilage detection, Arduino system, pH sensor, temperature monitoring, food safety*

INTRODUCTION

Background of the Study

Milk is one of the most widely consumed beverages globally due to its high nutritional value. However, it tends to spoil easily due to microbial contamination. The shelf life of pasteurized milk is measured between 12 to 14 days under cold conditions, but it differs with warm temperatures. Once the milk is stored under 32 °C for an hour, it is recommended to dispose of the milk as it would pose a silent risk in households and businesses (Dairy Food Safety, n.d.).

These contaminations may pose health risks and economic losses, especially when spoilage is not monitored and detected early. Improper storage or exposure to inconsistent temperatures are possible causes to accelerate milk spoilage. Spoiled milk shows changes in temperature, pH level, and gas concentration, which serve as indicators of microbial activity. Monitoring the parameters through sensor-based systems enables early detection of spoilage.

Many consumers still rely on smell, taste, or expiration dates to check if milk is spoiled. Some also look for changes in color or texture. However, these signs usually appear when spoilage has already progressed. Because of this, early detection is important to prevent foodborne illness and reduce food waste (Davis, 2025). Without reliable tools, households and small vendors may throw away safe milk too early or fail to detect spoiled milk in time.

Without reliable tools, households and vendors face difficulties in making accurate judgments, which leads to early disposal of safe milk or delayed detection of spoiled milk that poses health risks.

Existing studies have shown that sensors and IoT technologies can aid in monitoring food quality, providing faster and more reliable results. These innovations have emerged as a response to the fast-paced movement of globalization, as individuals become more aware of food distribution, including its composition and the food waste, along with its spoilage.

Additionally, adding this feature is intended to prolong shelf life and detect spoilage in real time, especially with handling dairy products for everyday and commercial consumption (Weston et al., 2021).

Arduino provides a low-cost platform that can integrate sensors to detect changes in temperature and pH, making it suitable for real-time milk monitoring. As a microcontroller, it serves as the central unit that collects, processes, and interprets data from multiple sensors.

Although there are promising innovations with sensors and IoT for food quality monitoring, the lack of action and specification on milk spoilage detection is what keeps these innovations from staying only as a prototype. Mainly, many innovations focus only on fruit and vegetable detection, not extending to goods that are used in daily life.

Additionally, the affordability of the detector is also being measured, which is the most common factor that researchers must consider, keeping in mind that this development is targeted for a household and commercial setup. Furthermore, considering the systems used to develop these prototypes are deemed as hard to navigate, which is not a good indicator for an easy-to-use detector for early detection of milk spoilage in dairy distribution.

This study aims to develop an Arduino-based smart prototype that can monitor milk in real time, detect early signs of spoilage, while integrating sensors such as pH level for the substance's liquid solution, and a temperature—DS18B20 sensor, considering the conditions in which the milk was stored. These sensors are developed to help ensure food safety while reducing waste, as this step is not only for the benefit of the technology but also for the environment in which we live.

Objectives of the Study

The study aims to design, develop, and evaluate an Arduino-based smart prototype capable of detecting pasteurized milk spoilage in real time through the monitoring of pH and temperature. Specifically, it seeks to:L (1) Develop a fully functional prototype by integrating the Arduino microcontroller with a pH sensor and a DS18B20 temperature sensor to monitor milk quality under different storage conditions. (2) Evaluate the performance, accuracy, and compatibility of the pH and temperature sensors—individually and when operating simultaneously—in detecting spoilage indicators in pasteurized milk. (3) Assess the prototype's reliability in classifying milk into three spoilage statuses (fresh, spoiling, and spoiled) based on real-time sensor data, and determine its overall accuracy across multiple testing intervals. (4) Analyze the relationship between pH changes, temperature exposure, and the observed spoilage progression to validate the effectiveness of the prototype for practical household and commercial use.

Literature Review

Milk Spoilage and Quality Assessment

Temperature control is a must to maintain the quality of the milk, and it also helps indicate the conditions of which and how the milk was spoiled. From that, a study from Dairy Food Safety (n.d), tackled that pasteurized milk will only last for about 12 to 14 days under cold conditions, roughly 4 °C or lower. However, milk that is stored in storage with 32 °C conditions for an hour can pose threats and risks in terms of health. (Undeniably Dairy, n.d.).

Milk nutrients are also prone to contamination, where aflatoxins and heavy metals pose significant health risks. Existing laboratory techniques for detection are accurate, they are often slow, costly, and require skilled personnel. Hence the potential use of nanotechnology to enable faster, portable, and more efficient methods for milk quality assessment (Darwesh et al., 2025).

pH-based methods are widely used in detecting food spoilage. For instance, Silva et al. (2022) propose that a pH-based colorimetric assay can serve as an indicator of microbial load in milk by correlating pH deviations with bacterial presence, while Jaganivash et al. (2020), the correlation among pH, acidity, volatile organic compounds (VOCs), temperature, and humidity in raw cow milk during storage reveals their potential as indicators of spoilage.

Recent studies also highlight the existence of bacteria in milk even in cold storage. According to Ahmed et al. (2024), Pseudomonas fluorescens also thrive even under chilled temperatures. In addition, findings from Lan et al. (2025) found bacterial growth, dominated by Streptococcus and Acinetobacter, increasing after day 13 of cold storage.

Furthermore, Hashim et al. (2022) reported that milk spoilage can be detected through pH, sensory changes, image analysis, and machine learning methods. Correspondingly, Mao (2025) highlights the shift to smart and automated methods. Mao (2025) emphasizes microbial contamination, poor temperature control, such as inadequate cooling, and defects in packaging as the primary causes of milk spoilage.

These causes may pose health risks and threats, from acute gastrointestinal issues to chronic effects such as immune dysfunction and toxin exposure.

Recent studies identified pH, temperature, and VOCs as key indicators of milk spoilage (Silva et al., 2022; Jaganivash et al., 2020; Hashim et al., 2022). Microbial activity also occurred during milk spoilage, which was further confirmed by Ahmed et al. (2024) and Lan et al. (2025), who observed bacterial growth in milk even under chilled storage.

To address these challenges, Mao (2025) and Hashim et al. (2022) emphasized smart containers and automated detection for better food safety. Supporting this, Arduino-based systems (Deen et al., 2023; Sari et al., 2024) demonstrate real-time monitoring of food spoilage, proposing practical and low-cost solutions for milk spoilage detection.

Sensor Technologies for Food Quality Monitoring

Jayan et al. (2023) highlighted that gas sensors can detect spoilage gases such as ammonia and volatile organic compounds (VOCs) in real time, enabling rapid assessment of milk freshness. Building on this, Mani et al. (2025) emphasized the use of gas and pH sensors in intelligent packaging systems to continuously monitor spoilage gases and acidity changes.

Both studies underscore the importance of real-time monitoring for food safety, though challenges such as sensor drift, calibration difficulties, and performance under varying storage conditions remain, suggesting the need for further technical improvements.

Recognizing these limitations, researchers have explored more complex electronic sensing systems. Gil et al. (2025) discussed e-nose, e-tongue, and e-eye technologies, noting that combining them, for example, by integrating e-nose with e-tongue or e-eye, enhances the accuracy of food quality assessments. Yet, this approach introduces challenges, including complex data processing, sensor fusion issues, and sensitivity to environmental changes.

In contrast, studies by Jayan et al. (2023) and Mani et al. (2025) focused on individual spoilage indicators, highlighting the spectrum between specialized and multi-sensor approaches.

To make monitoring more practical and affordable, microcontroller-based systems have been developed. Deen et al. (2023) created an Arduino-based system to detect spoilage in bananas, apples, tomatoes, milk, and curry, showing that milk freshness could be assessed through changes in odor and acidity. Similarly, Mohammed et al. (2018) developed a pH sensor prototype using Arduino to monitor meat spoilage under different temperatures.

Expanding this concept, Sari et al. (2024) introduced a multi-parameter Arduino Mega system for milk, addressing global dairy waste, although it remains limited to basic milk types.

Despite these technological advances, the wide adoption of food sensors remains limited. Weston et al. (2021) noted that most sensors still target single parameters like temperature, humidity, gases, or pH, which restricts their comprehensiveness. This observation aligns with Jayan et al. (2023) and Mani et al. (2025), where targeting specific spoilage factors was effective but limited in scope.

Meanwhile, Gil et al. (2025) and Sari et al. (2024) demonstrate that integrating multiple sensors improves both accuracy and versatility, suggesting that the future of food monitoring lies in multi-parameter systems capable of adapting to diverse conditions.

Several studies have developed smart food monitoring systems using sensors and microcontrollers. For example, Deen et al. (2023) created an Arduino-based system that detects spoilage in fruits, vegetables, and milk by measuring odor and acidity. Sari et al. (2024) developed a multi-parameter monitoring system for dairy products. While these systems show promising results, many focus on multiple food types or involve complex sensor combinations. These observations highlight the need for a simpler and more focused monitoring system designed specifically for pasteurized milk.

Microcontroller-Based Smart Packaging for Food Safety

Mkhari et al. (2025) examined the rapid development of intelligent packaging systems, highlighting sensors, indicators, and RFID technology for improved food preservation. They also emphasized nanotechnology, showing that nanoscale materials strengthen packaging and reduce environmental impact, allowing it to protect food and extend freshness, especially for perishable products like milk.

Palanisamy et al. (2024) expanded these technologies with Automatic Identification and Data Collection systems that monitor temperature, pH, gases, and microbial activity to assess freshness. They explored time–temperature indicators, pH-sensitive films, and gas sensors for carbon dioxide and ammonia, which detect spoilage through color changes or optical responses. Combined with microcontrollers, these technologies enable real-time monitoring.

Building on these ideas, Neelima et al. (2025) studied sensor-based systems tracking temperature, humidity, light, and gas levels to detect early spoilage. They tested MQ3 gas sensors for ethanol and methane, integrated with an Arduino platform that displayed results on an LCD and sent mobile notifications. The system works well, but needs adjustment for different foods, as each produces unique spoilage compounds.

Garg et al. (2023) applied a similar Arduino-based approach using MQ3 sensors to detect methane, adding a Wi-Fi module for app monitoring and results on a 16×2 LCD. Unlike Neelima et al., they relied only on MQ3 sensors and suggested adding temperature, pressure, and moisture sensors for better accuracy. These studies show that Arduino systems are reliable for spoilage detection but perform best with diverse sensors and food-specific designs.

Overall, Mkhari et al. (2025) and Palanisamy et al. (2024) focused on material innovations and diverse sensors, while Neelima et al. (2025) and Garg et al. (2023) emphasized microcontroller-based gas detection. All highlight combining multiple technologies to enhance intelligent packaging reliability.

Future research should develop food-specific systems, particularly for milk, monitoring pH, ammonia, and volatile compounds. Microcontroller-based designs targeting these factors can improve safety, extend shelf life, and reduce waste while maintaining quality.

Research Framework

Theoretical framework

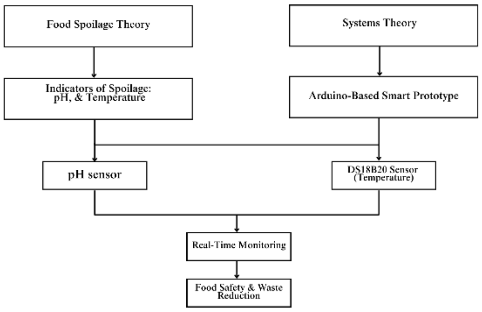

Figure 1. Theoretical Framework

This study is anchored by two main theoretical foundations: Food Spoilage Theory and Systems Theory. Food Spoilage Theory, introduced by Louis Pasteur, explains that microorganisms cause milk spoilage by breaking down proteins and lactose, producing compounds such as ammonia (NH_3), carbon dioxide (CO_2), and acids that lower pH. These changes justify the use of sensors like pH and DS18B20 (temperature) for monitoring spoilage.

Meanwhile, Systems Theory by Ludwig von Bertalanffy (1968) views the Arduino-based smart prototype as a system with inputs (milk samples), processes (sensor readings and data interpretation), and outputs (real-time spoilage detection). Together, these theories strengthen the foundation of developing a smart prototype for early and reliable milk spoilage monitoring.

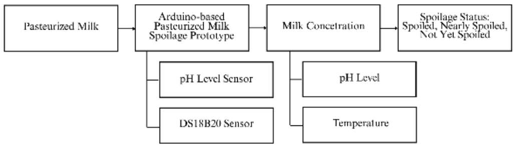

Figure 2. Conceptual Framework

This conceptual framework illustrates how sensor readings from DS18B20 (temperature sensor), and a pH sensor contribute in determining the spoilage status of pasteurized milk. These readings are processed by an Arduino-based smart prototype, which interprets the data to assess the freshness and spoilage of pasteurized milk. Storage conditions may influence the accuracy of the assessment.

Pasteurized milk serves as the subject being monitored, which provides a basis for sensor readings and spoilage assessment through Arduino-based milk prototype for spoilage monitoring.

Scope and Limitations

The study will focus on the development and testing of an Arduino-based prototype designed to detect spoilage in milk. The system will integrate two main sensors: a pH sensor (to monitor changes in acidity), and the DS18B20 temperature sensor (to measure ambient storage temperature). These sensors will work together to track critical parameters such as pH level, and temperature that indicate milk spoilage.

The scope of the study is limited to pasteurized milk-based beverages and does not extend to raw milk, flavored milk products, or other types of food and beverages.

The prototype will be tested under practical storage conditions, particularly room temperature environments. Some samples will initially be refrigerated before testing to observe how temperature changes affect spoilage. However, the study will not test other environmental factors such as humidity, direct sunlight, or different storage containers. However, certain limitations may affect its performance. The system will not account for all external factors that may influence milk spoilage, such as varying humidity, light exposure, or handling practices.

In addition, the sensors used may have limitations related to calibration and accuracy. The results of this study are therefore confined to monitoring selected indicators and may not represent all possible variables influencing milk quality.

METHODOLOGY

Research Design

This study used an experimental-developmental research design, which combined creating a prototype and evaluating its performance.

The developmental part focused on designing and building an Arduino-based smart container with pH and temperature sensors to detect milk spoilage signs and the milk's status. This included setting up the sensors, calibrating them, and ensuring the prototype functioned properly.

The experimental part involved testing the prototype on different pasteurized milk samples over time. The data collected from the sensors was analyzed to evaluate how accurately and effectively the prototype could detect milk spoilage. The results helped determine the potential of using the prototype for monitoring milk in household or commercial settings.

Materials

The materials used in the development of the prototype include the following: (1) Arduino Nano ATmega328P microcontroller. (2) PH-4502C liquid pH sensor with E201-BNC electrode. (3) DS18B20 waterproof digital temperature sensor. (4)16×2 LCD display with I2C interface. (5) Jumper wires. (6) Breadboard. (7) Light-emitting diodes (LEDs).

Methodological Framework

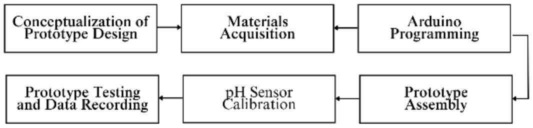

Figure 3. Methodological Framework

The development of the Arduino-based smart prototype involved the conceptualization and design of the system, followed by the acquisition of the necessary materials. The Arduino was programmed to process and display readings from the integrated sensors, specifically the pH sensor and DS18B20 temperature sensor, which were essential for detecting milk spoilage.

After assembling the sensors and components, the pH sensor was calibrated using standard buffer solutions to ensure accurate and precise measurements, with the calibration results integrated into the Arduino code.

The prototype was then tested using pasteurized milk samples, with multiple measurements taken to ensure accuracy and reliability, confirming the system's capability for real-time monitoring and early detection of milk spoilage.

Parameters

This study focused on detecting spoilage in pasteurized milk by monitoring two key parameters. The parameters tested include pH level and temperature.

A pH sensor monitors acidity, as fresh pasteurized milk typically has a pH ≥ 6.5 (Fox & McSweeney, 2015; Rosca et al., 2019), which decreases as bacterial activity produces lactic acid (Parveen et al., 2023). Milk with a pH of 6.0–6.4 is considered to be in the early stages of spoilage, while a pH ≤ 6.0 indicates that the milk is definitively spoiled.

The DS18B20 digital temperature sensor monitors storage conditions. Milk stored at ≤ 7 °C is considered within the safe zone and represents the optimal storage condition (Fröhlich et al., 2017). Temperatures between 7.1–15 °C fall within a moderate-risk zone, where microbial growth accelerates and spoilage may occur more quickly. Exposure above 15 °C constitutes a high-risk zone, significantly promoting bacterial proliferation and increasing the likelihood of spoilage (Cornell Dairy Extension, 2023; Fröhlich et al., 2017).

Both sensors were interfaced with an Arduino microcontroller, which continuously processed the data for real-time monitoring. Changes in pH or temperature were detected immediately, and the system provided instant alerts through a display when thresholds were exceeded. Unlike traditional sensory inspection or laboratory testing, this setup enabled continuous, automated monitoring, allowing early detection of spoilage, reducing health risks, and minimizing milk wastage.

Schematic Diagram

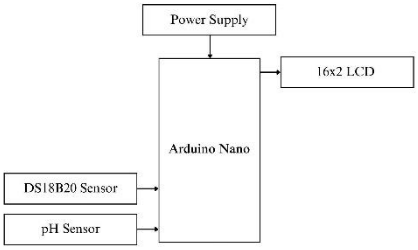

Figure 4. Schematic Diagram

The diagram illustrates the framework of the prototype device. Arduino Nano served as the main microcontroller responsible for receiving, processing, and transmitting data.

The pH sensor and DS18B20 temperature sensor were connected to the Arduino Nano as primary input devices. They collected data on milk acidity and temperature, which functioned as key indicators of spoilage. The collected data were transmitted to the Arduino Nano, where they were processed and compared against predefined spoilage thresholds.

The processed readings were displayed on a 16x2 LCD with an I2C interface, providing real-time information on milk quality. Additionally, an LED was integrated to serve as a visual alert, indicating when the milk exceeded the spoilage thresholds or when specific status changes occurred.

Arduino Programming

The Arduino microcontroller was programmed using the Arduino IDE to control the sensors and process real-time data from the system. The program continuously reads values from the pH sensor and DS18B20 temperature sensor, comparing them against predetermined threshold values for spoilage detection. A decision-making algorithm filtered out noise using moving averages and triggered alerts when readings indicated potential spoilage.

Live sensor readings and status alerts were displayed on a 16×2 LCD with an I2C interface, providing users with real-time monitoring information. LED indicators were also used to signal milk spoilage status: red indicated spoiled milk, yellow signified nearly spoiling milk, and green represented fresh milk. The LCD was programmed to cycle through multiple pages to enhance clarity and user guidance. The pH Level page displayed the current pH reading, while the Spoilage Status page indicated the milk's condition based on pH, showing "Safe to Drink!" for fresh milk, "Nearly Spoiled" for spoiling milk, and "Do Not Drink!" for spoiled milk. The Temperature page presented temperature readings only when the milk was fresh or nearly spoiling, while the Temperature Risk page identified whether the milk was in a "High Risk/Risk Zone" with the reminder "Keep in Cool Area," or in a "Safe Zone" with the reminder "Stay in Cool Area." This programming enabled automatic and continuous monitoring of pasteurized milk, delivering real-time indicators of spoilage and storage conditions without requiring manual intervention.

Implementation and Device Testing

The prototype was systematically assembled, beginning with the proper wiring of components to the Arduino Nano using jumper wires. The pH sensor was connected to an analog pin, while the DS18B20 temperature sensor was attached to a digital pin with a pull-up resistor to ensure stable readings. To optimize pin usage, the 16x2 LCD with I2C interface was integrated using jumper wires to display real-time data.

After assembly, the program was uploaded to the Arduino using the Arduino IDE, enabling the system to read and process sensor data and display processed information on the LCD.

Sensor Calibration

Before testing, the pH sensor was calibrated using standard pH buffer solutions of 4.01 and 6.86. For each buffer, 20 readings were taken to calculate the slope and intercept, which were then integrated into the Arduino code to ensure accurate pH measurements throughout testing.

Trial Runs

Following calibration, initial trial runs were conducted to verify the functionality of all components. This included assessing sensor responsiveness, confirming the accuracy of displayed readings, and observing the LED indicators for spoilage status—green for fresh, yellow for nearly spoiling, and red for spoiled. Necessary adjustments, particularly in the code, were made to ensure smooth communication between hardware and software components. By the end of this phase, a functional prototype was established, capable of monitoring milk quality indicators in real time.

Device Testing

Five milk samples were used to evaluate the prototype under varying conditions, with each sample tested five times at 12-hour intervals over a 48-hour period. The samples were selected to represent different storage histories and stages of spoilage, allowing the researchers to observe how the prototype responded to fresh, early spoiling, and fully spoiled milk. Repeating the measurements five times per sample helped improve data reliability while keeping the procedure manageable within the available time and resources. Specifically, Sample 1 consisted of freshly purchased milk maintained at room temperature throughout the testing period. Sample 2 was purchased two days prior and initially stored under refrigeration, then kept at room temperature after the first test. Sample 3 was also purchased two days prior but initially stored without refrigeration before being maintained at room temperature after the first test. Sample 4 was purchased seven days prior and initially refrigerated, then transferred to room temperature after the first test. Lastly, Sample 5 was purchased two weeks prior, initially stored unchilled, and subsequently kept at room temperature after the first test.

During testing, the sensors continuously monitored pH and temperature in real time. Data were collected for each interval, allowing trends in spoilage progression to be analyzed across samples and storage conditions. The combination of pH readings, temperature trends, and LED indicators provided a comprehensive assessment of milk quality, enabling evaluation of the prototype's accuracy, reliability, and responsiveness in detecting spoilage. This approach highlighted the system's potential for practical, real-time monitoring while identifying areas for further refinement.

Accuracy and Effectiveness Testing

The accuracy and effectiveness of the smart milk spoilage detection system were evaluated through sensor calibration, status classification, and measurement consistency.

pH Calibration

The pH sensor generates analog readings that vary according to milk acidity. Calibration was performed using standard buffer solutions with known pH values (e.g., pH 4.0, 7.0, and 9.0). A linear regression approach was applied using the slope-intercept formula:$y = m x + b$. Where y is the actual pH value, x is the raw analog reading, m is the slope, and b is the intercept. The slope and intercept were calculated using:

$$\mathrm{m} = \frac{6.86 - 4.01}{Ave.Analog8.86 - Ave.Analog4.01} \text{ or}$$

$$\mathrm{m} = \frac{4.01 - 6.86}{Ave.Analog4.01 - Ave.Analog6.86}$$

$$\text{and } b = 4.01 - m(Ave.\ Analog4.01) \text{ or}$$

$$b = 6.86 - m(Ave.\ Analog4.01),$$

where average analogs are calibration points from the standard buffers. The resulting equation converts raw sensor readings into accurate pH values.

pH Status Classification and Effectiveness

The calibrated pH readings were classified into three categories: (1) FRESH: $\mathrm{pH} \geq 6.5$ (2) SPOILING: $6.0 \leq \mathrm{pH} < 6.5$ (3) SPOILED: $\mathrm{pH} < 6.0$

The system's effectiveness was evaluated by comparing its classification against observed status. Effectiveness was calculated as: $\text{Effectiveness } \% = \frac{number\ of\ Aligned\ Classified\ Sample\ Test}{Total\ Number\ of\ Trail\ Runs} * 100$

Measurement Consistency

To assess precision, repeated pH measurements for each milk sample were used to calculate the mean and standard deviation (SD):

$$Mean\ (x) = \frac{\sum_{\mathrm{i}} x}{n} \text{ and SD} = \sqrt{\frac{\sum(xi - x)2}{n-1}}$$

where x_i represents individual readings and n is the number of measurements per sample. This ensured that the sensor provided reliable and consistent readings.

Compatibility Testing

Compatibility testing focused on ensuring that all system components worked together seamlessly.The pH sensor was integrated with the Arduino microcontroller, LEDs, and LCD display. Integration tests then verified that pH readings triggered the correct status messages and LED indicators in real-time. Lastly, continuous operation was observed to ensure proper synchronization between data acquisition, processing, and display outputs.

Ethical Considerations

Safety, integrity, and responsible conduct were prioritized throughout the development and testing of the Arduino-based prototype. Pasteurized milk samples were used solely for experimental purposes and were handled carefully to avoid any health risks, while spoiled milk was properly disposed of to prevent contamination and environmental impact.

During validation and testing, the researchers followed established laboratory safety protocols described in published procedures to ensure proper handling of samples, sensors, and equipment. All electronic components—such as the Arduino board, pH sensor, and temperature sensor—were assembled and tested using appropriate safety practices to minimize risks including overheating, short circuits, or electrical faults.

Data collected from the sensors were recorded truthfully, processed accurately, and reported without fabrication or manipulation. Environmental responsibility was also observed by minimizing electronic waste, reusing components when possible, and selecting safe, non-toxic, and durable materials for the prototype housing.

The prototype is not intended to replace official laboratory-based food safety evaluations but rather to demonstrate a practical method for supporting safe monitoring practices through early detection of spoilage. By upholding honesty, safety, and adherence to recognized research guidelines, the study maintains credibility and contributes meaningfully to scientific and educational development.

RESULTS AND DISCUSSION

This section presents the results of the calibration process, spoilage monitoring, accuracy evaluation, and classification performance of the Arduino-based milk spoilage detection prototype. The findings show how the system responded to changes in pH and temperature and how these measurements contributed to determining milk freshness across different samples.

Calibration Results

Calibration ensured that the pH sensor produced accurate and stable readings before it was used to detect milk spoilage. Two buffer solutions with known pH values of 6.86 and 4.01 were tested twenty times each to examine the sensor's consistency.

The sensor showed excellent stability in both buffer tests. For the pH 6.86 buffer, readings across twenty trials varied very little, with a standard deviation of 0.0173, indicating that measurements were consistently close to the expected value. This demonstrates the sensor's reliability for mid-range pH levels, which is important for assessing fresh milk. The pH 4.01 buffer also produced highly consistent readings, with an even lower standard deviation of 0.0139, showing that the sensor remained accurate in acidic conditions—critical for detecting spoiled milk. In both cases, the measured pH values closely matched the true buffer pH.

The calibration results demonstrated a correct linear relationship between the sensor's analog output and pH level. The calculated slope of -0.00948 indicates that the analog reading decreased as acidity increased, while the intercept of 14.684 was consistent across both buffers, confirming a proper calibration curve. These values were implemented in the Arduino code to accurately convert analog readings into pH measurements during testing.

Monitoring of Milk Samples Over 48 Hours

Five different milk samples were observed for 48 hours at 12 hour intervals. Their storage history varied, which allowed the prototype to be evaluated under different spoilage conditions. Each sample was checked for pH, observed status, and the prototype's verdict.

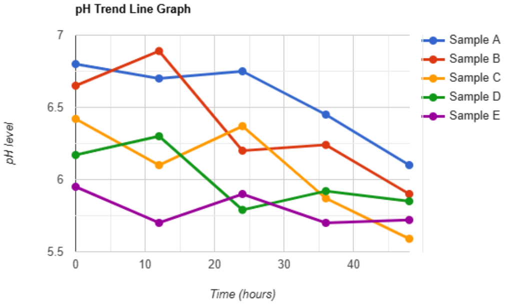

Figure 5. Trend of pH Readings During the 48-Hour Monitoring Period

The pH readings show a consistent downward trend across all milk samples throughout the 48-hour monitoring period. Fresh samples started with higher pH values and gradually decreased as spoilage progressed, while sample C showed an earlier and sharper drop, indicating faster deterioration. Samples D and E remained in the lower pH range from the start, confirming their spoiled or spoiling condition. Overall, the pattern demonstrates that acidity increases over time for all samples, clearly reflecting the natural progression of milk spoilage.

Accuracy of the Prototype

Out of 25 trials, 23 prototype classifications aligned with the observed status of the milk samples. An accuracy rate of 92 percent indicates that the system is dependable. The two misaligned results came from samples with borderline pH values, which can be difficult to distinguish in real settings.

Consistency of Fresh, Spoiling, and Spoiled Categories

To further examine the reliability of the pH sensor, the readings were grouped according to the prototype's verdict and analyzed based on mean and standard deviation.

The sensor demonstrated reliable performance across all stages of milk freshness, with consistent readings that reflect expected pH trends. Fresh milk samples exhibited an average pH of 6.758 with a low standard deviation of 0.087, indicating that the sensor consistently measured values within the fresh range. This confirms that the pH threshold for fresh milk is stable and dependable, providing a solid baseline for comparison with samples in later stages of spoilage.

Milk samples in the early spoiling stage showed slightly more variation, which is expected due to the transitional nature of this phase. The average pH of these samples was 6.2475 with a standard deviation of 0.140, demonstrating that the sensor could still detect subtle changes in acidity. These results indicate that the prototype is capable of identifying early spoilage conditions, offering a reliable indication before milk reaches full spoilage.

Fully spoiled milk samples were consistently below pH 6.0, with a mean of 5.81 and a standard deviation of 0.116. The low variation in readings confirms that the sensor accurately detected the increased acidity resulting from bacterial activity. Collectively, these results demonstrate that the prototype provides stable and dependable measurements across the full spectrum of milk freshness, effectively distinguishing between fresh, early spoiling, and spoiled samples.

Importance of Temperature in Spoilage Detection

Temperature was used to support the interpretation of pH data. Samples stored in cooler conditions below 7 degrees Celsius spoiled more slowly. Samples exposed to room temperature spoiled faster due to increased bacterial activity.

The temperature readings of the five milk samples reflected their initial storage conditions and the expected behavior of milk when exposed to room temperature over time. Samples A, C, and E, which were stored at room temperature from the start, maintained relatively stable temperatures between 28.5 °C and 30.4 °C throughout the 48-hour period. These consistently warm temperatures correspond with the faster rate of spoilage observed in their pH data, as higher temperatures accelerate microbial activity.

In contrast, Samples B and D began at significantly lower temperatures—7.0 °C and 6.5 °C, respectively—due to prior refrigeration. Over the next 12 to 24 hours, both samples gradually warmed to ambient conditions, reaching temperatures between 25 °C and 29 °C. This steady increase illustrates the transition from safe, chilled storage to conditions that promote bacterial growth and aligns with the delayed pH changes observed in these samples.

Once all samples equilibrated near room temperature, their temperatures stabilized with minimal fluctuations. This pattern confirms that the environment has the most significant impact on spoilage progression during the first 24 hours. Overall, the temperature data support the conclusion that exposure to temperatures above 15 °C increases spoilage risk, while chilled samples exhibit delayed spoilage until they reach ambient conditions. These results also highlight the utility of the DS18B20 sensor as a supplementary indicator that contextualizes pH changes and helps explain differences in spoilage rates among samples.

Overall Prototype Performance

The prototype showed reliable performance throughout the experiment. The pH sensor produced accurate and consistent readings, while the temperature sensor provided useful environmental context. The LCD and LED indicators displayed results clearly and responded correctly to each spoilage stage.

Compared with other sensor based food monitoring systems reported in previous studies, the prototype showed similar reliability while using fewer and simpler sensors. This suggests that accurate spoilage monitoring can still be achieved using a low cost and straightforward design.

The results demonstrate that the Arduino-based prototype can successfully detect milk spoilage in real time. It can classify milk as fresh, spoiling, or spoiled with strong accuracy. Its low-cost, simple components, and consistent performance make it suitable for both household and commercial use. The findings show that the system can help reduce milk waste, improve food safety, and give users a dependable way to check milk quality.

CONCLUSION

This research study successfully developed an Arduino-based smart milk spoilage detector that utilizes a pH sensor and a DS18B20 temperature sensor to monitor real-time changes in pasteurized milk. The prototype demonstrated reliable output, as shown by the correct display of sensor readings on the LCD and the activation of LED indicators according to the spoilage status.

To ensure reliability and accuracy, pH buffer solutions were used to calibrate the sensor before testing. The prototype achieved an overall accuracy of 92 percent, showing that it can correctly classify milk as fresh, spoiling, or spoiled.

The findings support its effectiveness by analyzing that pH sensors indicate a strong and consistent predictor of spoilage, and temperature serves only as a supporting factor that influences spoilage rate based on the way the milk was stored. Additionally, although the breadboard setup serves as a functional assembly of the prototype, the quality and long-term durability may be affected.

Overall, this development shows a simplified but reliable approach, not leaning on utilizing complex sensors, but instead using familiar ones seen regularly to test a product that people also use on a daily basis. This prototype also shows strong potential for a practical, low-cost, and real-time milk spoilage detector for household and commercial applications. Its high alignment rate, calibrated pH accuracy, and consistent temperature readings signify that it can help support early detection of spoilage, reduce milk waste, and improve food safety, which not only to consumers' well-being, but also to environmental sustainability.

Recommendations

Based on the findings of this study, several recommendations are proposed to enhance the performance and applicability of the prototype. Sensor stability and protection can be improved by upgrading the pH probe and temperature sensor with more durable protective casings to prevent damage during repeated use, while the use of food-grade materials is advised to ensure safer and more sanitary measurements. Future researchers are encouraged to increase the number and variety of milk samples, including different brands, storage conditions, and expiration dates, to strengthen the reliability and accuracy of results. Extending the monitoring period beyond 48 hours, such as up to 72 or 96 hours, may also provide a clearer understanding of spoilage progression over time. In terms of hardware, developing a more compact, durable, and portable design, along with incorporating a rechargeable power source, would improve usability. The integration of data logging features, such as Bluetooth, WiFi, or SD-card modules, is also recommended to enable automatic recording, real-time monitoring, and easier data storage. Additionally, exploring other spoilage indicators—such as turbidity, conductivity, or gas sensors—can enhance detection accuracy and provide a more comprehensive analysis. Future developments may also focus on designing a smart container or storage system with built-in sensors, allowing continuous and hands-free monitoring of milk spoilage in practical, everyday settings. Lastly, regular calibration of the pH sensor is essential to maintain measurement accuracy, particularly for long-term use or repeated testing.

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