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Smart Milk Quality Monitoring System: IoT-Driven Sensor and Data Analytics Interface

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Abstract: Since agriculture plays such a significant role in India's economy, the dairy industry helps the country. Milk is a valuable food for human mortal beings. Quality milk must not contain any contaminants but, for the purpose of increasing the amount of milk some contaminants are included which can decrease the nutritional quality of milk. Farmers supply milk for the preparation of dairy items, and their wages are based on the quality of the milk.The dairy business has an acute problem with regards to guaranteeing milk quality since the assessment techniques used are intensive and subjective.The people who are living more luxurious lives are following trends and customers' demands owing to the global fast-paced growth. This project aims to revolutionize milk quality assessment and management by integrating IoT and advanced data analytics into a comprehensive monitoring system. By utilizing sensors for pH, temperature, and color, the system detects adulter- ation and assesses milk suitability for consumption, including for infants. Real-time data is processed to provide actionable insights through an intuitive user interface, empowering farmers to make informed decisions. The objectives are to enhance milk quality, protect consumer health, and support agricultural sustainability. Expected outcomes include improved milk safety, increased farmer competitiveness, and promotion of sustainable farming practices, ultimately ensuring safe and nutritious milk for consumers. Consequently, India's agricultural lifestyle needs to be improved.

Keywords: *Dairy Sector, Adulteration, IoT (Internet of Things), Sensors, Real-Time Data, Agricultural Sustainability, Consumer Health.*

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I. INTRODUCTION

The dairy industry plays a pivotal role in global agriculture, contributing significantly to nutrition and economic stability. However, maintaining high milk quality remains a complex and labor-intensive challenge. Traditional methods for assessing milk quality are not only time-consuming but also heavily reliant on subjective judgment, which can lead to inconsistencies and potential health risks for consumers.This project introduces an innovative solution that combines new hardware and software technologies in order to transform milk quality evaluation and control. Ensuring the quality and safety of milk is paramount for consumer health and agricultural sustainability. This project leverages the Internet of Things (IoT) and advanced data analytics to create a comprehensive milk quality monitoring system. By employing multiple sensors, including pH, temperature, and color sensors, this system can detect adulteration, such as water contamination, and assess the suitability of milk for various uses, including infant consumption. The sensors continuously monitor critical parameters, and real-time data collected from these sensors are processed and analyzed to provide accurate and actionable insights. The core of this system is its ability to deliver real-time monitoring and early detection of any deviations from established quality standards. For instance, abnormal pH levels or unexpected temperature fluctuations can indicate spoilage or contamination. Additionally, the color sensor can identify any unusual discoloration, which is often a sign of adulteration. Data analytics algorithms interpret these sensor readings, comparing them against established quality benchmarks to ascertain the purity and nutritional value of the milk. A key feature of this innovative system is its user-friendly interface, designed specifically for farmers. This intuitive interface presents the analyzed data in an easily understandable format, enabling farmers to make informed decisions quickly. By acting promptly on the insights provided, farmers can enhance milk quality and safety, protecting consumer health and maintaining their reputation and competitiveness in the market.

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Ultimately, this project aims to empower farmers with cutting-edge technology, promoting sustainable farming practices and supporting the agricultural community. By ensuring the highest quality of milk production, this system contributes to the overall goal of delivering safe and nutritious milk to consumers, thereby fostering trust and reliability in the dairy industry.

➢ *Motivation and Related Work*

The literature survey gives a brief overview of the various machine-learning models and methods implemented for road safety analysis. This helps in identifying the gaps in the already existing systems and helps in identifying the particular features of this application which will help bridge the gaps

II. RELATED WORKS

S. Saravanan, et. al., (ICICCS, 2021).” Smart Milk Quality Analysis and Grading Using IoT ”. Maintaining the data of each depositor’s milk and analyzing it in this Paper is a very big challenge. The outcome of this problem can be established in this notion. Their goal is to create and implement a microcontroller- based system for tracking and evaluating milk parameters. colorful detectors are employed for detecting these variables. In order to decide milk chastity, many dairies base only on incorrect CLR tests. The price will automatically be calculated when the quality of the milk has been established.The database will also be simplified with all the aspects of the milk’s price. In the future automated era, this system will be significantly useful because it’s cheap and efficient [1].

A. Zakeri, et. al., (IEEE Access, 2021). ”Early Discovery System for visionary operation of Raw Milk Quality an Australian Case Study”. Within this Paper, the authors bandied for evaluation and preventing milk having a high microbiological indicator from moving further downstream in a dairy force chain, as exploration is taking a reactive station. They argue that if the object is to maximize milk life when it comes to quality, then such a solution isn’t the fashionable way of doing things. They propose a visionary strategy that monitors the factors of temperature and position, which are the building blocks of the bacteria in milk. The condition at which the storehouse tank will hold the milk in accordance with norms is also determined based on this information. The actual condition of the tank is also checked with this status, and if they are different, it’ll encourage the growers to take necessary preventive actions to control the quality of the milk. visionary operation created by Raw A rule- based system and machine literacy methods are employed to simulate the milk quality strategy. Level of perfection They apply it to milk in order to test our strategy and demonstrate how it can be applied. a ranch in Queensland, Australia [2].

Shubhangi Verulkar, et. al., (JETIR, 2020), ”Milk Quality and Volume Checker”. Authors have explained drugs can validate the quality and quantum of milk through an Internet of effects(IoT)- based system. The spread of origins will speed up, and the milk will possess an unfavorable smell if it’s stored in a storehouse for several days. The well-being of humans is gravely threatened by these contaminated milk- producing bacteria. To prevent unborn conditions, society immediately requires milk surveillance. The principal thing of this design was to create a detector- grounded electrical system for monitoring the geste of various composites in milk that can alter the rates of pure milk. In accordance, a monitoring system is required to detect and identify milk deterioration. By employing a combination of detectors to monitor the milk properties, this research demonstrates an innovative system of milk quality analysis [3].

Sumitra Goswami, et. al., (IJAEB, 2021), ”Arduino-Grounded Milk Quality Monitoring System”. Authors narrate the devel- opment and application of an Arduino regulator-grounded system for the discovery and analysis of milk parameters. The Developed system is light and low. It responds quickly and consumes minimal electricity to function. It can therefore be applied for mobile operations. unborn sweats will focus on enhancing the system’s overall delicacy. It’s also possible to minimize the size of the system and maximize mobility so that it can be used freely in the field [4].

S. Priya et. al., (IJTRD, 2020), ”Milk Quality Tester”. The authors, in this Paper, examined and presented a slice-edge milk quality surveillance system based on Smart Sensor tech- nology. The prime source of all new-born ’s diet is milk; thus, it’s essential to monitor kiddies’ security. The prime ideal of the design is to generate products that determine the safety and quality of milk consumed. In order to find out various parameters of milk, this research utilizes smart detector tech- nologies. For testing whether milk is hot or cold, temperature detectors are utilized.To characterize the pH of milk, a pH detector is utilized. It might be configured by utilizing the protein content, however, in case of the presence of melamine in milk. Consequently,all these detectors were incorporated into the casing, and the monitoring recommendation shows the affair outside(LED). With Bluetooth gadgetry, they can send a report to your smartphone regarding milk quality [5].

Rajkumar G. et. al., ”IoT Grounded Milk Monitoring System forDiscovery of Milk Contamination”, In this Paper, assaying the milk of each depositor and storing the data manually is a gigantic task. The outcome of this problem can be established in this concept. Their target is to design and implement a microcontroller- based system for monitoring and evaluating milk parameters. Some factors are pH, CLR, SNF and yield of milk. colorful detectors or probes are applied in measuring all these variables. To check the chastity of milk, several dairies determine solely on non-accurate CLR and content of fat testing. Nevertheless, based on this idea, the milk can be graded based on any value of milk parameter.

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Automatically, its cost will be calculated once quality of the milk has been calculated. The database will also be streamlined with all details of the price of the milk. The stoner will snappily acquire it through the simple mobile function whenever they require it. In the automated future world, this system will be immensely useful because it's cost-effective and efficient [6].

Yadav,S.N., et. al., (2012). "Design of Milk bedded system for dairy growers". They argue that if the object is to maximize milk life in quality, then such a method isn't the chic action. They Propose a futuristic approach that monitors the metrics of temperature and position, which are the building blocks of the bacteria in milk. The status under which the storehouse tank needs to keep the milk according to norms is also calculated with the help of this information. The actual condition of the tank is also matched with this status, and if they are different, it'll make the growers take the required preventive actions to control the quality of the milk. visionary operation created by Raw A rule- based system and machine literacy methods are employed to emulate the milk quality strategy. Level of perfection.The pH in a milk sample is sensed by a pH sensor. The milk pH must range from 6.5 to 6.8. The gas detector is able to explain microbial activity in milk or measure toxic gas emigrations from a milk sample. The milk temperature is measured by a temperature sensor, and the FAT is measured using the light scattering principle.LLEDs are applied to release shafts of light, and LDRs apply to determine scattering of such similar shafts. If a milk sample test tube is installed in between LED and LDR when used in this FAT dimension module, a shaft of light(either released from LED) moves through the milk test tube. If a ray of light traverses through a milk sample, the milk disperse it. The milk sample taken by Light Dependent Register diffuses light, and this light diffuses from the milk sample taken by Light Dependent Resistor. The LDR resistance changes as the light diffused from the milk sample changes, and the data measured is sent to the regulator board. If the milk contains an advanced fat content [7].

M Sujatha P, et. al., "Visible Spectroscopy Analysis of Fat Content in Milk using LabView", A data monitoring and milk quality analysis system on the grounds of a microcontroller is built The key parameters of milk such as pH, CLR, FAT, and SNF are regulated by this system. CLR is determined through the utilization of a lactometer. SNF value is obtained with the help of FAT chance and CLR value. The article presented the design and production procedure of a low-cost seeing fashion based on a radio-frequency excitation electromagnetic planar detector [8].

Chavan R et. al., "Comprehensive Assessment of colorful Milk Parameters Using Bedded and IoT Based Systems. They designed a system of wireless communication between the shop robotization system and the garc¸on. They applied IoT and data mining to develop a milk robotization machine. This system lowers total costs without adding productivity [9].

A. Limitations

Here are the limitations of each work mentioned above in three lines:

- The proposed system relies on various sensors to determine milk quality, but sensor accuracy and calibration are critical for consistent results. Manual intervention may still be required to adjust the system in case of erroneous readings. Additionally, it lacks a comprehensive approach for milk adulteration detection.
- The system relies heavily on temperature and location parameters to monitor milk quality, which may not be sufficient to detect all quality issues. The effectiveness of the approach is limited by environmental conditions and sensor reliability. The system may also face scalability issues for large-scale dairy operations.
- The monitoring system presented is highly dependent on IoT connectivity, which may lead to interruptions in data collection due to network issues. The system also lacks a detailed analysis of milk quality beyond basic parameters such as temperature and pH. Power consumption could be a concern for prolonged use in remote areas.
- The Arduino-based milk quality monitoring system faces limitations in terms of scalability for large-scale dairy farms. The precision of the system may not be sufficient for highly sensitive milk quality measurements. The system's portability could be improved further for better field use.
- The system depends on basic sensors and may not detect more complex contaminants or adulterants in milk. Bluetooth communication could be prone to interference, affecting the real-time transmission of data. The system's overall accuracy and reliability could be improved by integrating more ad- vanced technologies.
- The system relies on basic sensor technology for measuring milk quality, which may not be highly accurate in detecting subtle variations. The scalability of the system for widespread adoption in diverse dairy farms remains a challenge. Fur- thermore, external environmental factors could affect sensor performance.
- The proposed system for optimizing milk storage conditions may struggle in areas with unstable internet connections or inadequate infrastructure. Additionally, it may not be applicable to small-scale dairy producers due to high implementation costs. The reliance on only a few parameters may miss other important milk quality indicators.
- The system's reliance on visible spectroscopy may not provide the level of accuracy required for all types of milk quality analysis. The technology might not be affordable or feasible for all dairy producers, especially in rural settings. Limited sensor integration could hinder comprehensive milk quality monitoring.
- The IoT-based milk assessment system requires constant connectivity and may not be reliable in areas with poor internet access. The system's cost could be prohibitive for small-scale dairy farmers, and the implementation

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complexity might deter adoption. Data security and privacy concerns could arise with the wireless communication aspect.

B. Research Gaps Identified

Here are the identified research gaps for each work mentioned:

The research lacks integration of advanced technologies like machine learning for better milk quality prediction. There is also a gap in addressing the impact of environmental factors on sensor readings. Additionally, the system's ability to detect adulteration and contamination remains unexplored.

[10]The study does not explore the application of additional parameters beyond temperature and location to improve milk quality prediction accuracy. Furthermore, the scalability of the system to accommodate large dairy operations is not addressed. There is a need for research on enhancing sensor robustness in varying environments.

The system focuses mainly on basic quality parameters but lacks in-depth analysis of milk adulteration or contamination. Moreover, the integration of more advanced communication protocols for better data reliability and real-time monitoring is not covered. Future research could focus on improving power efficiency for long-term usage.

The research does not investigate the optimization of sensor calibration for varying milk quality conditions. The system's ability to scale to larger dairy farms or different types of milk processing plants remains unexplored. Additionally, future work could explore reducing the system's dependency on external devices for power and control.

The system lacks a comprehensive framework for detecting adulterants and other contaminants in milk. The research also does not address the challenges of data accuracy in rural settings where connectivity may be unreliable. More research is needed to explore the integration of advanced sensor technologies for better precision.

While the research explores basic sensor-based monitoring, it does not consider integrating more sophisticated analytical techniques to improve the accuracy of milk quality assessments. The system's potential for adaptation to different dairy farming practices remains unexplored. There is also a gap in optimizing the system for use in resource-limited environments.

The study does not address the economic feasibility of implementing the proposed system for small-scale dairy producers. Additionally, the impact of real-world environmental variations on the proposed milk quality monitoring system is not fully explored. More research is needed to integrate a wider range of sensors for more comprehensive milk quality analysis.

III. PROPOSED SYSTEM ARCHITECTURE

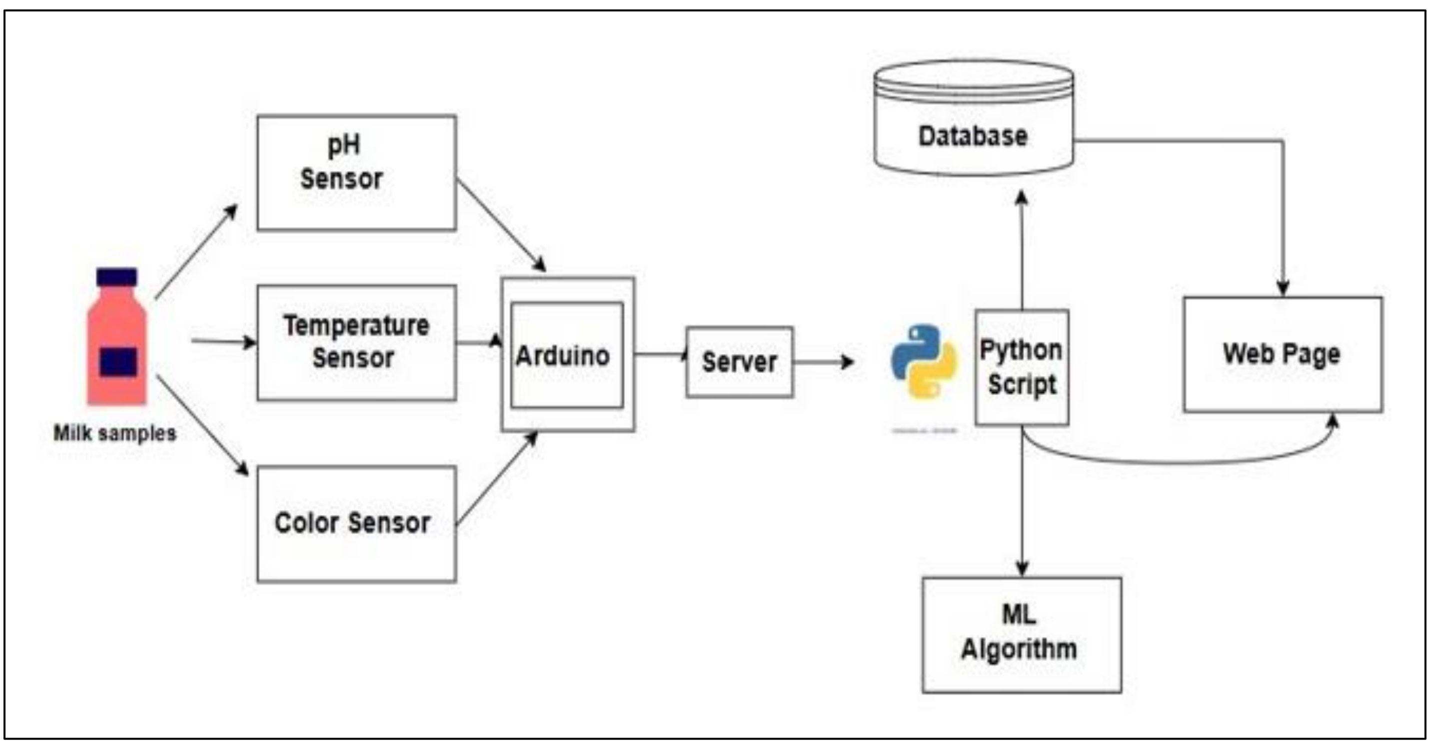

Fig 1: Architecture Diagram

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The Real-time IoT Enabled Smart Milk Monitoring system implements a multi-layered architecture designed for scalability, reliability, and real-time performance. The system architecture can be broken down into several key components:

A. Hardware Layer

IoT devices installed transmit real-time quality data (pH, Color, Temperature) Arduino hardware modules for reliable data transmission. Devices maintain continuous communication with the central system.

B. Data Storage Layer

➢ *Real-Time Database:*

- Stores real-time milk quality tracking data
- Optimized for high-frequency writes and real-time data access
- Maintains current milk sample ID, temperature, and timestamps

➢ *Relational Database (mySQL): Stores Persistent Data Including:*

- User Details
- Sensor Data

C. Backend Services Layer

Python handling data processing and business logic Key functionalities include:

- Real-time data processing
- Data optimization
- Proximity calculations
- Data Analysis
- Data Visualization

D. Interface Layer

- *User Interface:* Web application built with php
- Real-time data monitoring
- Data management
- Quality Tracking

E. Communication Flow

- Hardware components continuously transmits data to real-time database
- Backend services process and analyze incoming data
- Real-time analytics are generated based on specified rules
- Analysis are then used for clear visualization
- Interfaces update automatically with new data
- Historical data is archived in the relational database

IV. RESULTS AND DISCUSSIONS

The Real-time IoT Enabled Smart Milk Monitoring System is a groundbreaking innovation that leverages the power of IoT technology to revolutionize the dairy industry. By continuously monitoring critical parameters like pH, temperature, and color, the system can detect potential issues such as adulteration, contamination, and spoilage in real-time. This early detection capability empowers farmers and dairy processors to take immediate corrective actions, ensuring the delivery of safe and high-quality milk to consumers.

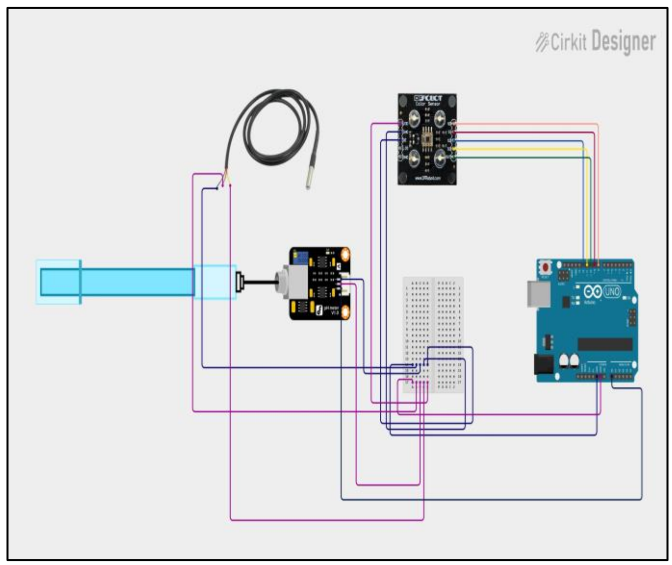

Fig 2: Circuit Diagram

The system's advanced data analytics algorithms process the collected data to identify deviations from established quality standards. By analyzing these deviations, the system can provide valuable insights, such as abnormal pH levels indicating potential contamination or temperature fluctuations suggesting spoilage. These insights empower stakeholders to make informed decisions, optimize operations, and reduce wastage.

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A. Graphical Representation and Analysis

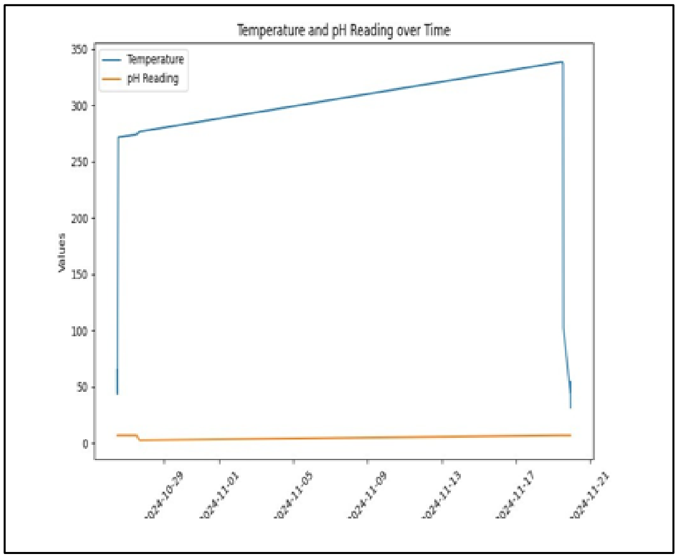

Fig 3(a): Line Plot

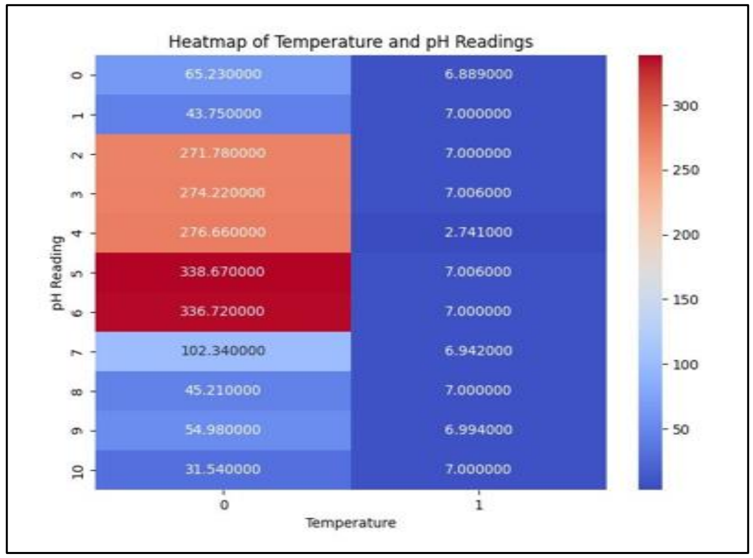

Fig 3(b): Heat Map

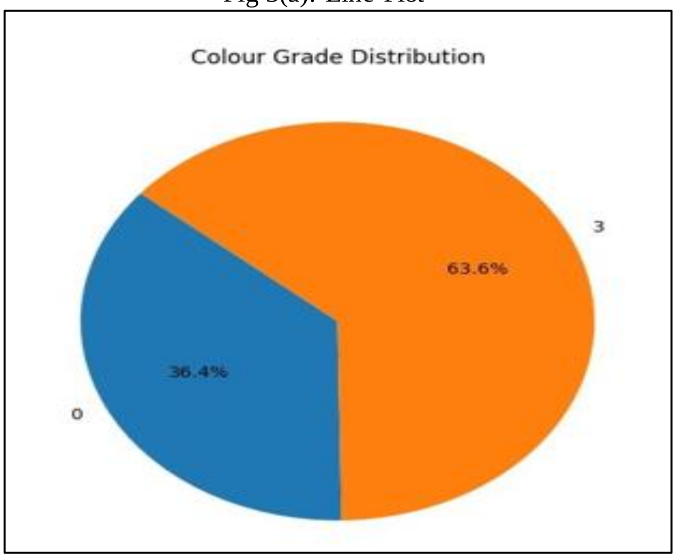

Fig 3(c): Pie Chart

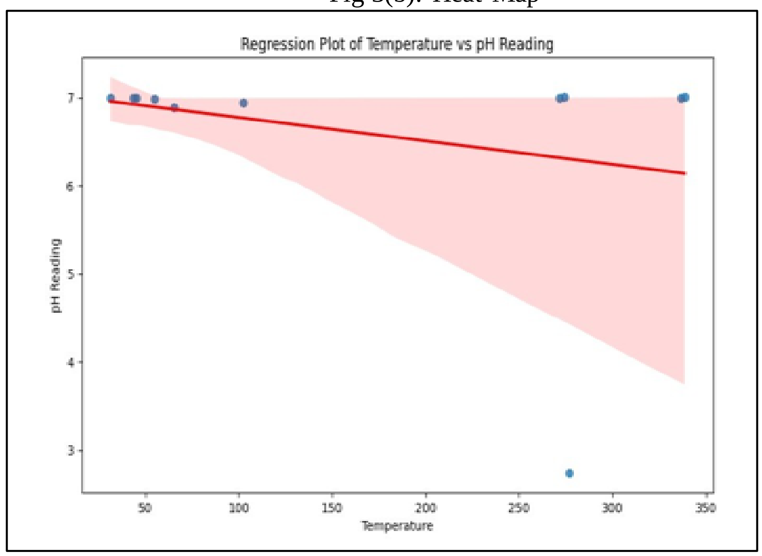

Fig 3(d): Regression Plot

Fig 3: Graphical Representations of Sensor Data for Analysis

Fig 3(a) illustrates the changes in milk temperature and pH over time, likely in a storage or transportation setting. The blue line indicates a gradual temperature rise, with a sharp increase toward the end, suggesting potential temperature control issues. In contrast, the orange line shows a stable, low pH, implying no drastic changes in milk acidity, which is a positive indicator of quality. For a smart milk quality monitoring system, this data is crucial. The temperature spike would trigger an alert to investigate and rectify any issues, while a concurrent drop in pH could signal bacterial growth and spoilage. Monitoring these trends provides valuable insights for optimizing storage conditions, minimizing spoilage, and ensuring milk quality. However, pH changes might lag behind temperature fluctuations, and other factors like contamination and milk composition can also influence pH. Although the graph highlights the dynamic relationship between temperature and pH, it does not account for these complexities alone. Integrating this data with additional sensor inputs and analytical models enhances the system's ability to provide accurate, real-time assessments of milk quality, ensuring timely interventions and better preservation outcomes.

Fig 3(b) visualizes the relationship between milk temperature and pH, with each cell representing a specific temperature-pH combination and its frequency. Higher color intensity indicates more frequent occurrences, offering insights into milk's behavior under various conditions. The temperature axis likely spans a storage-relevant range, while the pH axis reflects milk's slightly acidic nature. For a smart milk quality monitoring system, the heatmap aids in identifying optimal storage

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conditions by highlighting the most common temperature-pH combinations linked to high-quality milk. It also helps detect anomalies, such as unusual or infrequent combinations, which might signal spoilage or contamination. Furthermore, analyzing the distribution of readings can optimize handling and processing practices to maintain consistent milk quality. However, the heatmap has limitations: it may struggle with large datasets, where blending colors obscure patterns, and it only shows correlation, not causality, as pH is influenced by factors beyond temperature. Despite these challenges, the heatmap serves as a powerful tool for visualizing temperature-pH relationships in milk. When combined with additional sensor data and analytical models, it enhances the system's ability to detect spoilage, optimize storage, and ensure milk safety and quality in real-time applications.

Fig 3(c) visualizes the relationship between milk temperature and pH, where each cell represents a unique temperature-pH combination, and color intensity indicates its frequency. The temperature axis likely spans a storage-relevant range, while the pH axis reflects milk's slightly acidic nature. For a smart milk quality monitoring system, the heatmap aids in identifying optimal conditions by highlighting frequent temperature-pH combinations associated with high-quality milk, providing valuable insights for setting storage and processing parameters. It also helps detect anomalies, such as infrequent combinations, which may indicate spoilage, contamination, or other quality issues. Furthermore, analyzing the distribution of readings can reveal areas for improving milk handling and processing to maintain consistent quality. However, the heatmap has limitations: it may lose clarity with large datasets due to blending colors and only shows correlations, not direct causality, as pH is influenced by factors beyond temperature. Despite these challenges, the heatmap offers a visual tool to understand milk's behavior across varying conditions. Combined with additional sensor data and analytical models, it strengthens the system's ability to detect spoilage, optimize storage, and ensure milk quality, making it an essential component of modern milk monitoring applications.

Fig (d) illustrates the relationship between milk temperature and its pH level, with a red regression line highlighting the general trend. The negative slope of the line indicates an inverse relationship: as temperature increases, pH tends to decrease. The blue dots represent individual data points, showing some variability around the regression line, suggesting additional influencing factors beyond temperature. This relationship is crucial for a smart milk quality monitoring system. Changes in pH can signal spoilage, making the correlation a valuable tool for early detection. Predictive analysis using the regression line allows the system to anticipate expected pH values at specific temperatures, with deviations acting as potential red flags for abnormalities. Additionally, understanding this relationship supports process optimization, enabling better control of storage and processing conditions to maintain pH stability and extend shelf life. However, other factors like bacterial activity and milk composition also impact pH, and the observed variability in data points indicates that the regression model might not fully capture these interactions. Despite these limitations, the insights from this plot can significantly enhance spoilage detection, storage optimization, and overall milk quality assurance.

Furthermore, the system can contribute to building consumer trust by ensuring the quality and safety of milk products. By providing transparent and reliable information about milk quality, the system can enhance brand reputation and customer satisfaction.

While the system holds immense potential, it is essential to address potential challenges. Accurate sensor calibration and robust data analysis algorithms are crucial for reliable results. Proper training for farmers and dairy personnel is necessary to effectively utilize the system and interpret data insights. Additionally, the cost-effectiveness of the system should be carefully evaluated to ensure its widespread adoption.

In conclusion, the Real-time IoT Enabled Smart Milk Monitoring System represents a significant advancement in dairy technology. By prioritizing consumer safety, enhancing operational efficiency, and reducing wastage, this system has the potential to transform the dairy industry and ensure a reliable supply of high-quality milk.

V. CONCLUSION

The Real-time IoT Enabled Milk Quality Monitoring system has demonstrated its effectiveness in revolutionizing quality management. By leveraging IoT technology, real-time data processing, and user-friendly interfaces, the system has suc- cessfully addressed critical issues in safety, efficiency, and early detection.

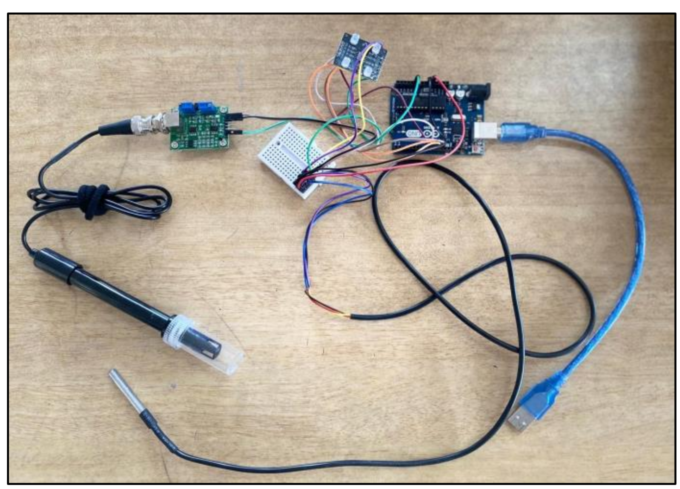

Fig 4: Hardware Setup

Milk Quality Results

Time	Milk Man ID	pH Value	Color Grade	CLR	Lactometer Reading	Total Grade
2024-11-19 23:00:34	5	7.000000000000002 (Alkaline)	[illegible]	32.2	Water is not mixed	0 - None of the conditions match
2024-11-19 22:49:45	4	6.994 (Alkaline)	[illegible]	37.8	Other substances are mixed to increase density	0 - None of the conditions match
2024-11-19 22:33:53	3	7.000000000000002 (Alkaline)	[illegible]	35.8	Other substances are mixed to increase density	0 - None of the conditions match
2024-11-19 13:46:52	2	6.942 (Alkaline)	[illegible]	46.2	Other substances are mixed to increase density	0 - None of the conditions match
2024-11-19 13:24:43	1	7 (Alkaline)	[illegible]	96.2	Other substances are mixed to increase density	0 - None of the conditions match
2024-11-19 12:04:43	12678	7.006 (Alkaline)	[illegible]	92.6	Other substances are mixed to increase density	0 - None of the conditions match
2024-10-27 16:12:18	12345678	2.7409999999999997 (Acidic)	[illegible]	80.2	Other substances are mixed to increase density	0 - None of the conditions match
2024-10-27 12:36:09	12348	7.006 (Alkaline)	[illegible]	80.6	Other substances are mixed to increase density	0 - None of the conditions match
2024-10-26 12:46:13	12457	7 (Alkaline)	[illegible]	83.2	Other substances are mixed to increase density	0 - None of the conditions match
2024-10-26 11:36:27	12345	7.000000000000002 (Alkaline)	[illegible]	6.6	Large amount of water is mixed	0 - None of the conditions match
2024-10-26 11:19:10	12131	6.888999999999999 (Alkaline)	[illegible]	230.8	Other substances are mixed to increase density	0 - None of the conditions match

Back to Dashboard

Fig 5: User Interface of Results

➢ *Key Achievements Include:*

- Significant improvements in consumer Safety
- Substantial increases in operational efficiency and re- source utilization
- Reduced Wastage and spoilage of quality milk
- Early detection and prevention
- Enhanced accountability for dairy industry owners
- Robust data-driven decision-making capabilities

The nature of the project has fostered community involvement, leading to continuous improvements and adaptations to diverse needs. This has made the system an attractive and cost-effective solution for Dairy Industry of varying sizes and resources. While challenges such as internet connectivity issues persist, the overall impact of the system has been overwhelmingly positive. The successful implementation across multiple industry demonstrates its scalability and adaptability.

➢ *Future Developments May Focus on:*

- Integrating machine learning for more accurate predictive analytics
- Enhancing offline capabilities for areas with poor connectivity
- Expanding the system to include additional sensor ser- vices

In conclusion, this project has not only met its initial objectives of improving health safety and efficiency but has also paved the way for broader applications of IoT and real-time monitoring in industry logistics. The positive outcomes observed suggest that similar systems could be beneficial in other sectors requiring precise logistics management and real-time tracking.

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