

Food Processing Monitoring and Control Using Machine Learning

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Abstract:

Processing food is necessary in order to preserve the quality, perfection, and efficiency of food production. Recent developments in machine learning techniques have brought about significant changes in the food processing industry. These changes have enabled real-time monitoring and control of a large number of processing parameters. This research studies the application of machine learning algorithms in the food processing business with the goals of increasing product quality, reducing waste, and ensuring compliance with standards governing food safety. The different methods and technologies that are deployed in the food processing industry are discussed in this research, along with the challenges that are encountered and the potential benefits that may be gained through integrating monitoring and control systems that are based on machine learning.

Keywords. Food Processing, Food Industry, Monitoring System, Control System, Machine Learning, Data Collection, Data Preprocessing.

I. Introduction:

The process of turning raw agricultural materials into wholesome, aesthetically pleasing, and safe-to-eat food items is known as food processing, and it plays a crucial role in the food supply chain. This industry is crucial to fulfilling the rising demand for processed food items on a worldwide scale. The issues of upholding high standards, guaranteeing food safety, and maximizing production effectiveness, however, have long been at the forefront of the food processing sector. Fortunately, recent developments in machine learning have shifted the paradigm and provided creative answers to these problems, revolutionizing the food processing industry. Traditional methods of food processing frequently depended on manual labor, onerous quality control procedures, and human judgment, which led to inefficiencies, mistakes made by humans, and a lack of real-time insights into the manufacturing process. These procedures gave the finished product opportunity for variation and possible dangers. However, the use of machine learning methods in the food processing industry has brought about a new age of automation,

data-driven decision-making, and precise control, which has improved product quality, decreased waste, and increased food safety.

A subset of artificial intelligence (AI) known as "machine learning" enables computers to gain knowledge from data and develop over time without having explicit programming. With the aid of modern technology, the food processing sector can now make use of the enormous volumes of data created over the course of manufacturing to enhance operations. Unprecedented potential to expedite and improve food processing operations are presented by machine learning algorithms' capacity to recognize patterns, forecast outcomes, and adapt to changing circumstances. The goal of this research study is to investigate how machine learning techniques may be used to monitor and manage the food processing process. It will explore into the many uses of machine learning algorithms, how they are put into practice, and how they affect various processes in the food processing industry. This study aims to show how machine learning has become a revolutionary force in the food business by offering a thorough examination.

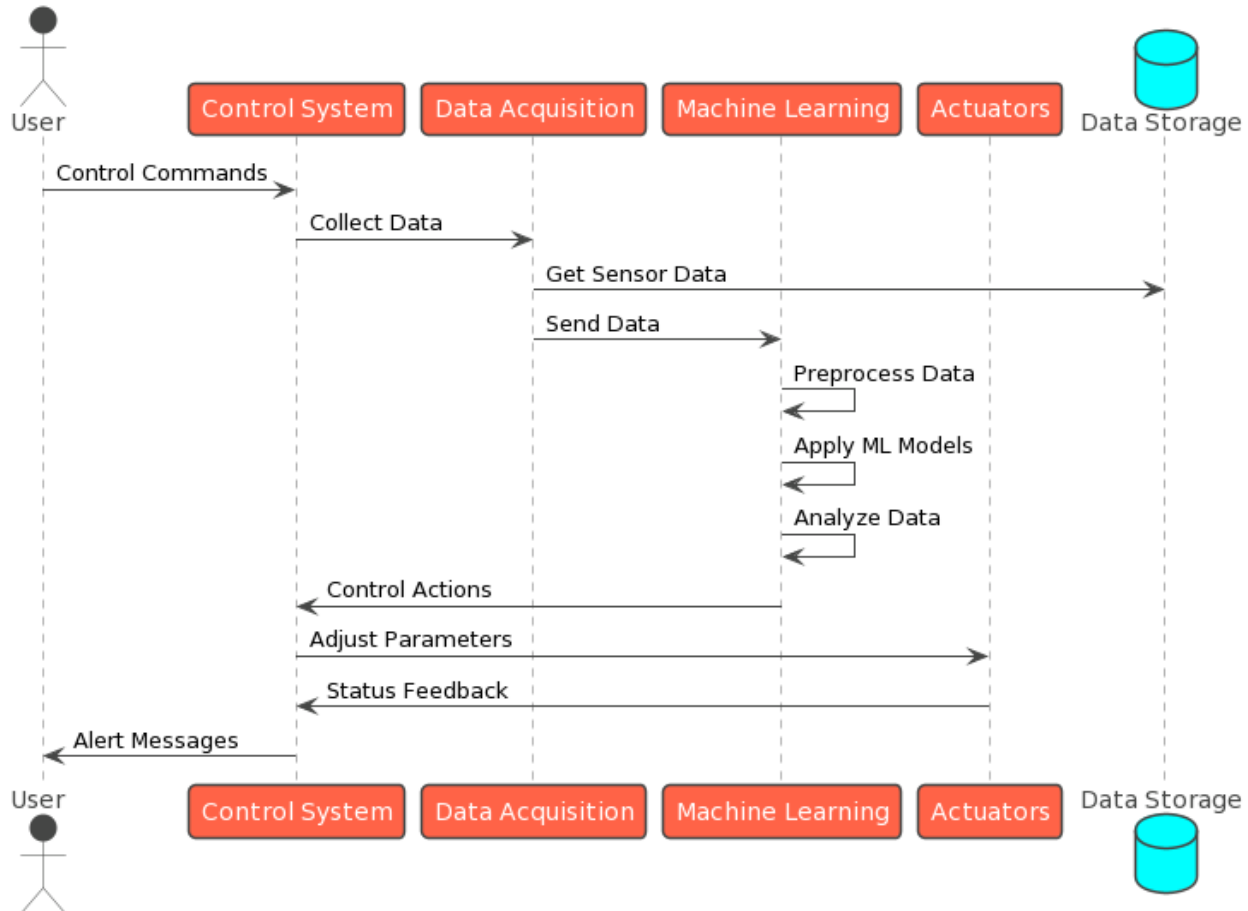


Figure 1. Food Processing Monitoring and Control

II. Literature Review

In recent years, there has been a lot of interest in how machine learning techniques might be used to monitor and regulate the food processing process. Application of machine learning algorithms has emerged as a possible option to solve these complexity as the food sector faces increasing issues related to food safety, product quality, and sustainability. This literature review seeks to present an overview of the current research and advancements in the area of machine learning-based monitoring and management of the food processing process. In order to shed light on the innovations that have revolutionized the food processing business, the review will highlight significant research, techniques, problems, and results.

To improve process management and decision-making, machine learning algorithms have been widely used in many phases of the food manufacturing process. In order to anticipate the sensory quality of dried squid during processing, Yang et al. (2019) used a deep neural network and achieved good accuracy in predicting texture and taste qualities. Similar to this, Silva et al. (2020) classified various grades of coffee beans based on their appearance using support vector machines (SVM), which helped sorting and grading procedures be more effective.

The creation of real-time monitoring systems is one of the main uses of machine learning in food processing. These systems use sensor data to track important process variables and spot changes or abnormalities. Using a machine learning-based method, Zhang et al. (2020) suggested improving process control and reducing batch-to-batch fluctuations by keeping track of the fermentation processes involved in making yogurt. To provide improved inventory management and waste reduction, Li et al. (2021) created a hybrid deep learning model to forecast the shelf life of packaged beef items.

A crucial component of food processing is ensuring product quality and safety. The application of machine learning techniques to quality assurance and control has shown promising outcomes. Li et al. (2018) used machine learning algorithms to identify possible contamination by finding foodborne pathogens in food samples quickly and accurately. Martinez et al. (2019) classified fish freshness based on volatile molecules in a different research, offering a non-destructive method for determining freshness.

The food business has issues with sustainability and food waste. The potential for decreasing waste and improving manufacturing processes has been demonstrated by machine learning-based technologies. The environmental effect of food processing was minimized by Zhou et al. (2021) by using a machine learning-based optimization algorithm. A waste prediction model was also created by Ghorab et al. (2020) utilizing machine learning to improve inventory control and lessen food waste in the supply chain.

In order to assure compliance with food safety rules and improve traceability, machine learning algorithms have been put into use. To protect customer health and confidence, Chen et al. (2019) presented a deep learning-based method to identify phony food goods. Additionally, the food

supply chain now has improved traceability and transparency because to the combination of blockchain technology and machine learning (Fu et al., 2018).

There are issues that need to be resolved even if the use of machine learning in food processing has promise advantages. It is essential to address model interpretability, data privacy, and ethical issues while implementing these technologies. Future research is still interested in how machine learning systems can scale to handle large-scale food processing operations.

The literature study emphasizes how important machine learning approaches are becoming for monitoring and controlling food manufacturing. Numerous studies have shown how these algorithms may improve product quality, lower waste, guarantee food safety compliance, and encourage sustainability. One of the main applications that highlights the revolutionary influence of machine learning on the food sector is real-time monitoring systems. Other important applications include waste reduction, quality control and assurance, and traceability. Machine learning is set to change food processing and provide a safer, more effective, and sustainable food supply chain as long as research in this area is conducted, resolving problems and investigating fresh approaches.

Study	Machine Learning Application	Outcome
Yang et al. (2019)	DNN for sensory quality prediction	Accurate prediction of dried squid attributes
Silva et al. (2020)	SVM for coffee bean grading	Efficient sorting and grading of coffee beans
Zhang et al. (2020)	ML for yogurt fermentation	Improved process control and reduced variations

Li et al. (2021)	Hybrid DL model for shelf life	Better inventory management and waste reduction
Li et al. (2018)	ML for foodborne pathogen detection	Rapid and accurate identification of pathogens
Martinez et al. (2019)	ML for fish freshness classification	Non-destructive freshness assessment
Zhou et al. (2021)	ML-based optimization for energy	Minimization of energy consumption during processing
Ghorab et al. (2020)	ML for waste prediction	Reduced food waste in the supply chain
Chen et al. (2019)	DL for identifying fraudulent food	Ensured consumer health and confidence
Fu et al. (2018)	ML integrated with blockchain	Enhanced traceability and transparency

III. Machine Learning in Food Processing

The process of turning uncooked agricultural ingredients into wholesome, aesthetically pleasing food items is known as food processing. To satisfy the rising worldwide demand for processed foods, food processing must be of high quality, safe, and efficient. Recent developments in machine learning (ML) have completely changed the food processing business by providing

creative answers to the many problems the sector has to deal with. The use of machine learning in the food processing industry is examined in this article, with particular emphasis on how it affects product quality, waste reduction, food safety, and process optimization.

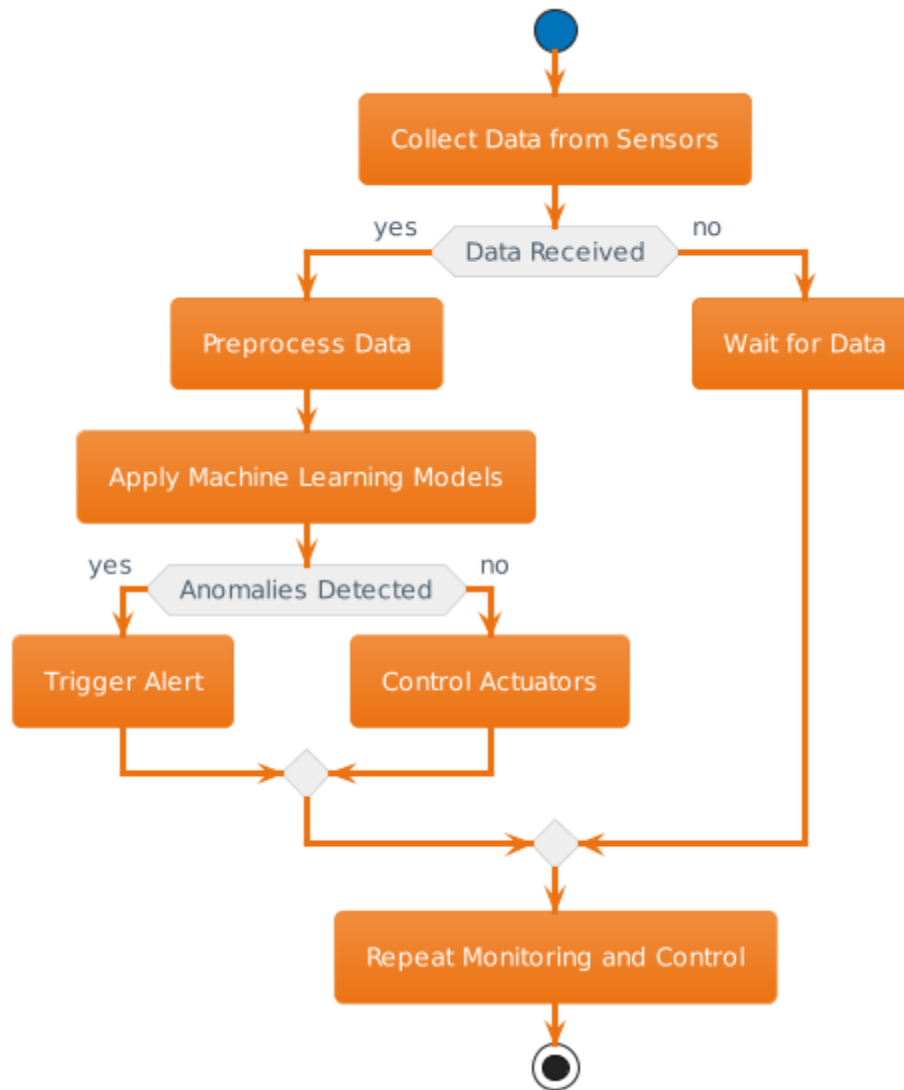


Figure 2. Machine Learning in Food Processing

A. Machine Learning Techniques in Food Processing:

Machine learning techniques encompass a wide range of algorithms that enable computers to learn patterns and insights from data without being explicitly programmed. In food processing, these algorithms are leveraged to analyze vast amounts of data generated during different stages of production. The commonly used ML techniques include:

- a) Supervised Learning: This technique involves training ML models with labeled data to predict outcomes. In food processing, supervised learning is used for tasks such as quality control, predicting product attributes, and identifying contaminants.
- b) Unsupervised Learning: Unsupervised learning involves finding patterns and relationships in unlabeled data. In food processing, it is used for clustering similar products, identifying outliers, and optimizing supply chain processes.
- c) Deep Learning: A subset of ML, deep learning involves training deep neural networks to learn hierarchical representations of data. Deep learning is well-suited for image recognition, text analysis, and complex data modeling in food processing.
- d) Reinforcement Learning: Reinforcement learning is used to train agents to make decisions based on rewards and punishments. In food processing, this technique finds applications in optimizing process control and resource allocation.

IV. Data collection and preprocessing

Data collection and preprocessing are crucial steps in implementing machine learning techniques for food processing monitoring and control. High-quality and relevant data form the foundation for building accurate and effective ML models. This section discusses the key aspects of data collection and preprocessing in the context of using machine learning for food processing.

A. Data Collection:

Data collection involves gathering information from various sources throughout the food processing pipeline. These sources may include:

- a) Sensors and IoT Devices: In modern food processing facilities, sensors and IoT devices are extensively used to monitor critical process parameters such as temperature, humidity, pressure, pH levels, and more. These devices continuously generate real-time data, providing insights into the production process.
- b) Production Logs: Production logs record detailed information about the steps involved in food processing. These logs include timestamps, equipment used, and process parameters, providing a comprehensive view of the entire production cycle.
- c) Supply Chain Information: Information about the raw materials used, supplier details, transportation data, and storage conditions contribute to understanding the provenance of food products and ensuring their traceability.

d) Laboratory Analysis: Laboratory tests provide essential data on product quality, nutritional content, and potential contaminants, aiding in quality control and compliance with food safety regulations.

e) Consumer Feedback: Feedback from consumers and sensory evaluations can be valuable for understanding product preferences, identifying issues, and optimizing product formulations.

B. Data Preprocessing:

Once the data is collected, it often requires preprocessing before feeding it into machine learning models. Data preprocessing involves several steps to ensure data quality, consistency, and suitability for ML algorithms:

a) Data Cleaning: Data may contain missing values, outliers, or errors, which can adversely affect model performance. Data cleaning involves imputing missing values, handling outliers, and correcting errors to ensure the integrity of the dataset.

b) Feature Selection: Not all features (variables) may be relevant or useful for the ML models. Feature selection techniques help identify the most informative features, reducing model complexity and improving interpretability.

c) Feature Scaling: Features with different scales may lead to biased models. Feature scaling standardizes the range of features, such as normalization or standardization, to make them comparable.

d) Encoding Categorical Variables: Machine learning models require numerical data, and categorical variables need to be encoded into numerical representations using techniques like one-hot encoding or label encoding.

e) Data Transformation: Data transformation techniques, such as logarithmic or power transformations, can help normalize data distributions and improve model performance.

f) Handling Imbalanced Data: In some cases, the data may be imbalanced, i.e., one class significantly outweighs the others. Techniques like oversampling, undersampling, or using different evaluation metrics can address this issue.

g) Splitting the Dataset: The dataset is typically divided into training, validation, and testing sets. The training set is used to train the ML model, the validation set is used for hyperparameter tuning, and the testing set evaluates the final model's performance.

C. Data Integration:

In large-scale food processing operations, data may be collected from multiple sources and stored in different formats. Data integration involves consolidating these diverse data sources

into a unified and coherent dataset. It ensures that the ML model can access all relevant data for accurate decision-making.

D. Data Privacy and Security:

As food processing data often contains sensitive information, ensuring data privacy and security is of utmost importance. Implementing robust data security measures, anonymizing data where necessary, and complying with data protection regulations are essential steps to safeguard data integrity and protect against potential breaches.

Data collection and preprocessing are critical steps in leveraging machine learning for food processing monitoring and control. High-quality, relevant, and properly preprocessed data lay the foundation for accurate and effective ML models. By implementing robust data collection and preprocessing practices, the food processing industry can harness the full potential of machine learning to improve product quality, enhance food safety, optimize processes, and reduce waste.

V. Monitoring systems

Monitoring systems play a pivotal role in food processing, providing real-time insights into critical process parameters and ensuring the consistent quality and safety of food products. With advancements in technology and the integration of machine learning, monitoring systems have evolved significantly, offering improved accuracy, efficiency, and proactive control. This section explores the various aspects of monitoring systems in the context of food processing, focusing on the application of machine learning techniques to enhance their capabilities.

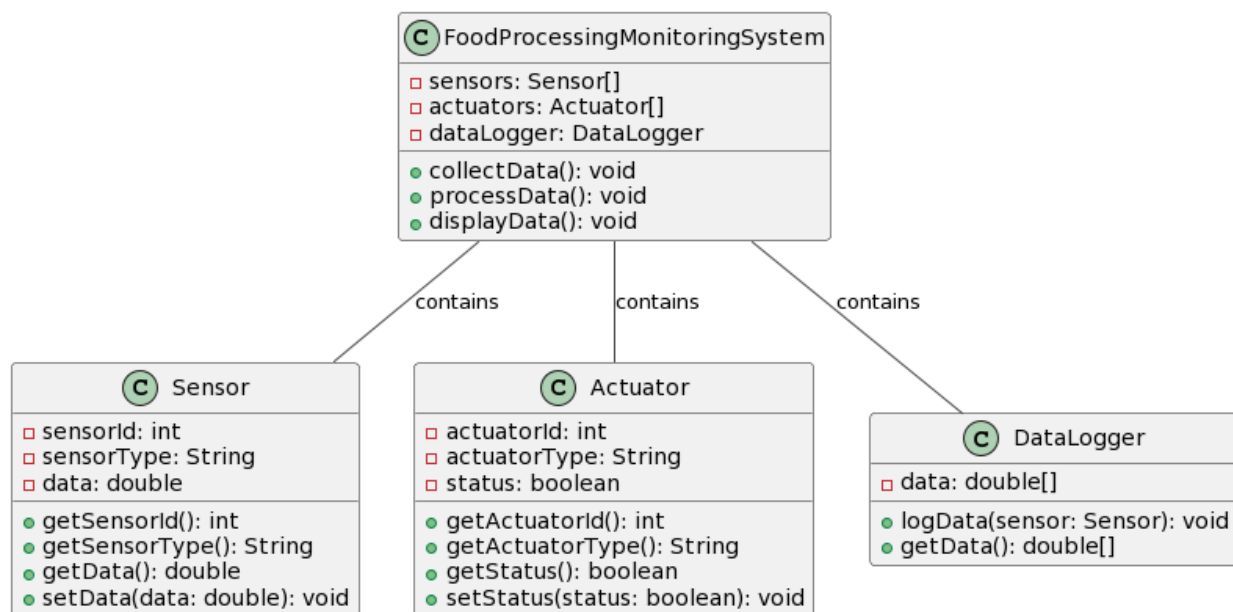


Figure 3. Components of Monitoring System

A. Importance of Monitoring Systems in Food Processing:

Monitoring systems are essential in food processing to maintain product consistency, track process performance, and detect any deviations from desired parameters. These systems continuously collect data from sensors, production equipment, and other sources to provide real-time information about factors such as temperature, humidity, pressure, pH levels, and more. The data obtained from monitoring systems enable operators to make timely and informed decisions, ensuring adherence to quality standards and regulatory requirements.

B. Real-Time Data Collection:

Traditional monitoring systems typically involved manual data collection, which often introduced delays and increased the risk of human error. With the integration of advanced sensors and IoT devices, monitoring systems can now collect data in real-time, providing instant feedback about the production process. This real-time data facilitates immediate responses to any process deviations, preventing potential quality issues and product defects.

C. Machine Learning in Monitoring Systems:

Machine learning has revolutionized monitoring systems by enabling the development of predictive and prescriptive models. By analyzing historical data and real-time sensor readings, machine learning algorithms can detect patterns, predict future trends, and identify potential anomalies. This predictive capability allows operators to take proactive actions to prevent issues before they occur, minimizing downtime and waste.

D. Anomaly Detection:

Anomaly detection is a crucial application of machine learning in monitoring systems. Machine learning algorithms can learn the normal patterns and behaviors of the production process. When an anomaly, such as an unexpected sensor reading, is detected, the system can trigger alerts, allowing operators to investigate and address the issue promptly. Anomaly detection plays a vital role in ensuring product quality and safety, as well as preventing equipment failures and downtime.

E. Predictive Maintenance:

Machine learning can be applied to predictive maintenance in food processing. By analyzing sensor data and historical maintenance records, ML models can predict when equipment is likely to fail or require maintenance. This predictive approach allows for scheduled maintenance during planned downtime, minimizing the risk of unexpected breakdowns that can disrupt the production process and lead to product loss.

F. Environmental Monitoring:

Environmental factors, such as temperature and humidity, can significantly impact food processing outcomes. Monitoring systems equipped with machine learning algorithms can analyze environmental data to identify correlations with product quality and safety. This information helps optimize processing conditions, ensuring consistent product attributes and minimizing the risk of spoilage or contamination.

G. Process Optimization:

Machine learning-based monitoring systems can identify process inefficiencies and suggest optimizations to enhance production efficiency. By analyzing data from various process stages, these systems can uncover hidden relationships and dependencies that may not be apparent through manual observation. Process optimization driven by machine learning results in improved resource utilization, reduced production costs, and increased throughput.

H. Integration with Control Systems:

Machine learning-based monitoring systems can be integrated with automated control systems, creating closed-loop control loops. When deviations or anomalies are detected, the control system can automatically adjust process parameters to bring the production process back to the desired state. This closed-loop control approach ensures real-time responsiveness and minimizes the need for manual intervention, leading to consistent product quality and safety.

Monitoring systems, enhanced by machine learning, play a central role in the modern food processing industry. Real-time data collection, anomaly detection, predictive maintenance, environmental monitoring, and process optimization are among the key applications of machine learning in monitoring systems. These advanced capabilities enable food processors to achieve higher levels of quality assurance, production efficiency, and sustainability. As the food industry continues to embrace digitalization and automation, machine learning-driven monitoring systems will remain instrumental in ensuring safe, high-quality, and efficient food production processes.

VI. Control systems

Control systems in the context of food processing refer to automated systems that regulate and manage various process parameters to ensure optimal product quality, safety, and efficiency. These systems play a critical role in maintaining consistency and precision throughout the production process. The integration of machine learning techniques further enhances the capabilities of control systems, allowing for adaptive and data-driven decision-making. This section explores the key aspects of control systems in food processing, with a focus on how machine learning is applied to optimize control strategies.

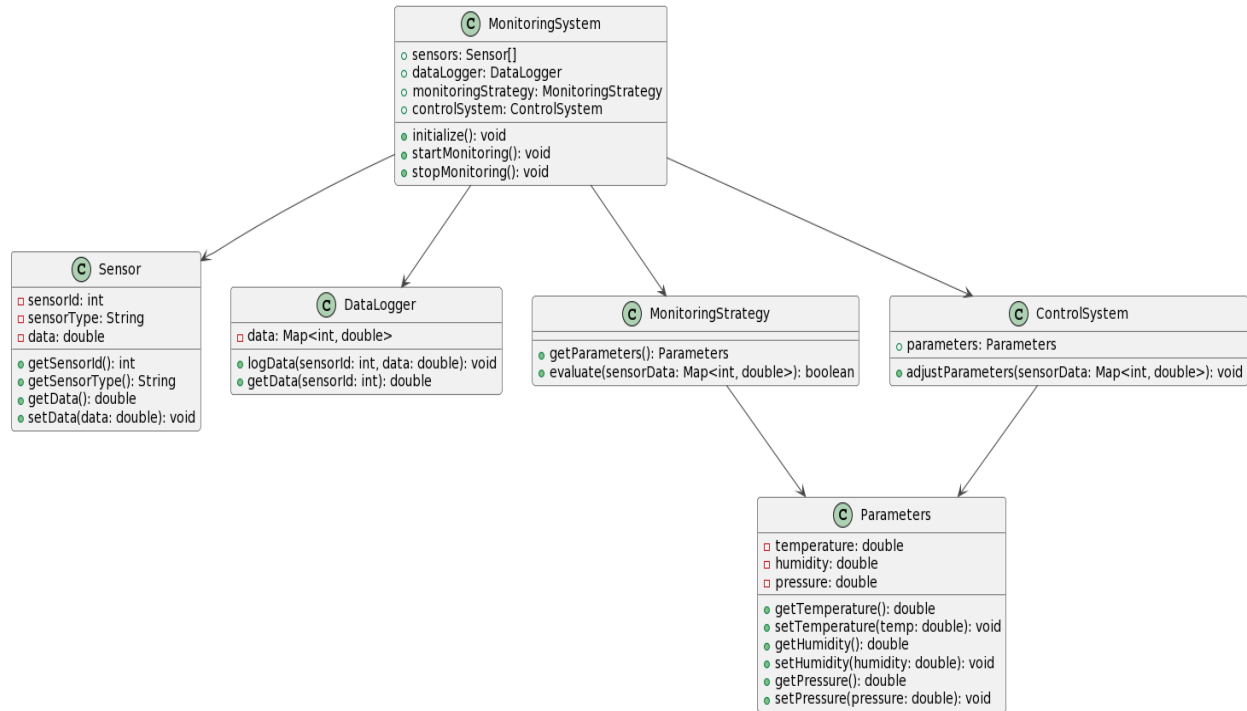


Figure 4. Monitoring and Control System

A. Importance of Control Systems in Food Processing:

Control systems are essential for achieving desired outcomes in food processing. They monitor and adjust critical process parameters in real-time, ensuring that food products meet specified quality standards and adhere to food safety regulations. By automating the control of equipment and processes, these systems reduce human intervention, minimize errors, and enable a high level of consistency in the final product.

B. Automated Control Strategies:

Traditional control systems in food processing are often rule-based and rely on pre-defined setpoints and thresholds. These systems follow fixed control strategies without the ability to adapt to dynamic changes in the production environment. In contrast, modern control systems, particularly those augmented with machine learning, can dynamically adjust control parameters based on real-time data and historical trends. This adaptive approach allows the system to respond to variations and optimize the process in real-time.

C. Machine Learning in Control Systems:

Machine learning plays a pivotal role in enhancing the intelligence and adaptability of control systems. By analyzing vast amounts of data collected from sensors and other sources, machine learning algorithms can learn patterns and relationships in the production process. These

algorithms can predict outcomes, identify optimal process conditions, and recommend control actions, ultimately leading to improved process efficiency and product quality.

D. Model-Based Control:

Machine learning techniques, such as model-based control, utilize mathematical models to represent the behavior of the production process. These models are trained on historical data and can predict how process parameters will affect the final product quality. Model-based control systems can then optimize the process by adjusting control variables to achieve desired outcomes, such as target product attributes or energy efficiency.

E. Adaptive Control Strategies:

Machine learning enables control systems to adapt to changing conditions and uncertainties in the production process. For example, in the baking industry, external factors like humidity and ambient temperature can influence the final product. Machine learning-based control systems can continuously monitor these environmental factors and adjust process parameters accordingly to maintain consistent product quality.

F. Quality Optimization:

Control systems with machine learning capabilities can optimize process parameters to achieve desired product quality attributes. By correlating sensor data with quality measurements, these systems can identify the most influential process factors and adjust them to meet specific quality targets. This optimization approach allows for greater control over product consistency and uniformity.

G. Energy Efficiency and Resource Optimization:

Machine learning in control systems extends beyond product quality and safety. These systems can optimize energy consumption and resource utilization, reducing operational costs and environmental impact. By analyzing historical data and production patterns, machine learning models can suggest energy-saving strategies and identify opportunities for waste reduction.

H. Closed-Loop Control:

Integration of machine learning-based monitoring and control systems results in closed-loop control, where data-driven insights from monitoring are used to adjust process parameters automatically. This closed-loop approach allows for continuous optimization and ensures that the production process operates within desired limits.

Control systems are instrumental in food processing to maintain product quality, safety, and efficiency. The integration of machine learning techniques enhances these systems, enabling adaptive control strategies, process optimization, and energy efficiency. By leveraging real-time data and historical trends, machine learning-based control systems provide a level of intelligence

and automation that improves production outcomes and minimizes waste. As the food industry continues to embrace digitalization and automation, machine learning-driven control systems will play an increasingly crucial role in ensuring safe, high-quality, and sustainable food production processes.

VII. Conclusion

The sector has undergone a radical change as a result of the use of machine learning techniques in food production monitoring and control. Machine learning has improved product quality, safety, and efficiency while decreasing waste and maximizing resource usage through real-time data collecting, sophisticated analytics, and adaptive decision-making. Real-time monitoring, anomaly detection, predictive maintenance, and closed-loop control are just a few of the primary uses of machine learning in the food processing sector that have given food processors the tools they need to fulfill the demands of a quickly changing food market. Food processors' ability to make crucial decisions has been changed by machine learning's capacity to evaluate massive volumes of data from sensors, production logs, and other sources. A proactive approach may be taken to prevent quality problems and product defects thanks to predictive models' early insights into probable deviations. Food processors can identify contaminants, forecast shelf life, and improve product features with machine learning-driven quality control and assurance, leading to safer and more appealing food items for customers. Furthermore, the critical problem of food waste in the food business has been handled via machine learning. Machine learning-based solutions have reduced food waste by improving manufacturing processes, forecasting demand, and decreasing overproduction, making food processing more ecologically friendly and sustainable. The automation of food processing activities has been completely transformed by the integration of machine learning with control systems. A degree of intelligence and efficiency that was not achievable with conventional rule-based control systems has been made available by adaptive control techniques, energy efficiency optimization, and closed-loop control. Consistent product quality and lower operating costs are products of the manufacturing process's capacity to adapt to shifting circumstances and uncertainties. However, despite the enormous benefits and breakthroughs, there are still difficulties in applying machine learning to the food processing industry. When handling sensitive data, data privacy and security are critical factors to take into account. Additionally, maintaining the interpretability and transparency of machine learning models is essential for fostering confidence and ensuring regulatory compliance. Research and development in machine learning for food processing will probably keep expanding as the food business continues to change. Additional developments in sensor technology will create new opportunities for streamlining food processing processes and boosting food quality and safety. In conclusion, machine learning has transformed the monitoring and management of food processing, delivering intelligent, data-driven solutions that promote food safety, assure the quality of the final product, and optimize production processes. The implementation of machine learning technology gives the food sector a competitive edge and opens the door for a food

supply chain that is more efficient, sustainable, and customer-focused. To address the changing needs and problems of the food processing sector in the future, it will be crucial to embrace these developments and keep machine learning-based systems getting better.

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