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The Design of an Integrated IoT and Artificial Intelligence System for Fish Quality Degradation Diagnosis

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Abstract

In post-harvest handling, fish quality assessment is typically carried out using traditional sensory observations, which are potentially resulting in inconsistent diagnoses. Furthermore, prior research has not fully integrated the Internet of Things (IoT) with artificial intelligence for fish quality diagnostics, and it frequently concentrates on a single quality metric. This study aims to design and evaluate an integrated system based on IoT and artificial intelligence using a Case-Based Reasoning (CBR) approach for diagnosing fish quality degradation. The developed system utilizes IoT-based sensors to monitor physicochemical parameters, such as temperature, pH, and gas indicators, with real-time data transmission to a cloud platform. The collected data are analyzed using a CBR model as a decision support system. Performance evaluation was conducted using 120 testing data under controlled storage conditions and validated through expert assessment. The results show that the system achieves a diagnostic accuracy of 92.5%, with precision of 91.8%, recall of 93.2%, and an F1-score of 92.5%. In addition, the system has an average data transmission latency of 0.87 seconds, enabling near real-time diagnosis. These findings indicate that the system provides accurate and efficient diagnosis of fish quality degradation and supports post-harvest quality management.

Keywords*: Internet of Things, Fish Quality Assessment, Quality Degradation*

Abstrak

Dalam penanganan pasca panen, penilaian kualitas ikan biasanya dilakukan menggunakan pengamatan sensorik tradisional, yang berpotensi menghasilkan diagnosis yang tidak konsisten. Lebih lanjut, penelitian sebelumnya belum sepenuhnya mengintegrasikan Internet of Things (IoT) dengan kecerdasan buatan untuk diagnostik kualitas ikan, dan seringkali hanya berfokus pada satu metrik kualitas. Studi ini bertujuan untuk merancang dan mengevaluasi sistem terintegrasi berbasis IoT dan kecerdasan buatan menggunakan pendekatan Case-Based Reasoning (CBR) untuk mendiagnosis degradasi kualitas ikan. Sistem yang dikembangkan memanfaatkan sensor berbasis IoT untuk memantau parameter fisikokimia, seperti suhu, pH, dan indikator gas, dengan transmisi data real-time ke platform cloud. Data yang dikumpulkan dianalisis menggunakan model CBR sebagai sistem pendukung keputusan. Evaluasi kinerja dilakukan menggunakan 120 data pengujian dalam kondisi penyimpanan terkontrol dan divalidasi melalui penilaian ahli. Hasil menunjukkan bahwa sistem mencapai akurasi diagnostik sebesar 92,5%, dengan presisi 91,8%, recall 93,2%, dan skor F1 sebesar 92,5%. Selain itu, sistem ini memiliki latensi transmisi data rata-rata 0,87 detik, memungkinkan diagnosis mendekati waktu nyata. Temuan ini menunjukkan bahwa sistem ini memberikan diagnosis yang akurat dan efisien terhadap penurunan kualitas ikan dan mendukung manajemen kualitas pasca panen.

Kata kunci: Internet of Things, Mutu Ikan, Kemunduran Mutu

Introduction

Fish quality degradation is a major challenge in postharvest handling and distribution, particularly in tropical countries where fishery products are highly perishable. Inadequate monitoring of storage and handling conditions can accelerate spoilage processes, leading to economic losses, food safety risks, and reduced consumer trust [1][2]. Therefore, accurate and timely assessment of fish quality is essential to ensure product safety and maintain market value [3].

Conventional methods for evaluating fish quality, such as sensory analysis and laboratory-based chemical testing, are widely used in both research and industry. However, sensory evaluation is subjective and highly dependent on expert experience, while laboratory-based methods require specialized equipment, trained personnel, and significant processing time [4][5]. These limitations reduce their effectiveness for real-time quality monitoring in large-scale distribution chains and remote fishery environments [6].

Recent advances in the Internet of Things (IoT) have enabled real-time monitoring of environmental and physicochemical parameters through interconnected sensor networks. IoT-based systems support continuous data acquisition, remote access, and scalable deployment, making them suitable for monitoring fish freshness indicators such as temperature, pH, and volatile compounds [7][8]. Several studies have demonstrated the effectiveness of IoT architectures in food quality monitoring applications [9]. Nevertheless, raw sensor data alone are insufficient to provide reliable diagnostic conclusions regarding fish quality degradation without intelligent data processing [10].

Artificial Intelligence (AI) techniques have been increasingly applied to transform sensor data into actionable knowledge. AI-based decision support systems are capable of identifying complex patterns, learning from historical cases, and providing consistent and objective diagnostic results [11]. When integrated with IoT infrastructures, AI enhances system intelligence by enabling automated diagnosis, adaptive learning, and predictive analysis of quality degradation processes [12]. Despite growing research on IoT-based monitoring systems and AI-based classification models, studies that comprehensively address the integrated design and performance evaluation of IoT–AI systems for fish quality degradation diagnosis remain limited. Most existing works focus on either sensor development or algorithm accuracy without evaluating system-level performance, such as reliability, latency, and scalability.This study addresses these gaps by presenting the design and performance evaluation of an integrated IoT and Artificial Intelligence system for diagnosing fish quality degradation. The proposed system combines real-time sensor data acquisition with an AI-based decision support model to provide accurate and efficient quality diagnosis. System performance is evaluated using quantitative metrics, including diagnostic accuracy, precision, recall, F1-score, and data transmission latency. The findings of this study are expected to contribute to the advancement of intelligent postharvest monitoring systems and support the development of smart fishery and food quality management applications.

Literature Review (optional)

a. Fish Quality Degradation and Conventional Assessment Methods

Fish quality degradation is a complex biochemical and microbiological process influenced by storage conditions, handling practices, and environmental factors. Deterioration in fish quality is commonly associated with changes in temperature, pH, microbial activity, and the accumulation of volatile compounds, which directly affect freshness and safety [13][14]. Conventional fish quality assessment methods include sensory evaluation, chemical analysis, and microbiological testing. While these approaches are widely accepted, they are often subjective, labor-intensive, time-consuming, and unsuitable for continuous or real-time monitoring [15][16]. Recent studies emphasize that reliance on manual inspection and laboratory-based testing limits scalability and responsiveness, particularly in large-scale postharvest distribution systems and remote fishery environments [17]. These limitations have motivated the development of automated and technology-driven solutions to improve accuracy, efficiency, and consistency in fish quality assessment.

b. Internet of Things (IoT) for Fish Quality Monitoring

The Internet of Things (IoT) has emerged as a key enabling technology for real-time monitoring in food quality and aquaculture applications. IoT-based systems utilize interconnected sensors to continuously collect environmental and physicochemical data, such as temperature, pH, dissolved gases, and humidity, which are critical indicators of fish freshness [18][19]. Several studies have demonstrated the successful deployment of IoT architectures for water quality monitoring in fish ponds, aquaculture systems, and cold-chain logistics [20][21]. IoT solutions provide advantages including remote accessibility, scalability, and real-time data transmission, enabling stakeholders to monitor quality conditions continuously and respond promptly to adverse changes [22]. However, most IoT-based fish monitoring systems primarily focus on data acquisition and visualization, offering limited analytical capability for interpreting complex quality degradation patterns [23]. As a result, IoT systems alone are insufficient for accurate diagnosis and decision-making without intelligent data processing mechanisms.

c. Artificial Intelligence for Quality Diagnosis and Decision Support

Artificial Intelligence (AI) techniques have been widely applied in food quality assessment to address the limitations of traditional analytical methods. Machine learning and intelligent decision support systems are capable of identifying hidden patterns, learning from historical data, and providing objective and consistent diagnostic outcomes [24][25]. Recent research highlights the effectiveness of AI models in classifying freshness levels, predicting spoilage, and supporting quality-related decisions in seafood and perishable food products [26]. AI-based approaches, when applied independently, demonstrate strong analytical performance but often rely on offline datasets and lack real-time data integration [27]. This disconnect limits their practical applicability in dynamic postharvest environments where continuous monitoring and rapid decision-making are required.

d. Integration of IoT and Artificial Intelligence

The integration of IoT and AI has gained increasing attention as a promising approach for developing intelligent monitoring and diagnostic systems. IoT provides continuous, real-time data streams, while AI transforms raw sensor data into actionable insights through automated analysis and learning capabilities [28][29]. Recent studies report that IoT–AI integration enhances system intelligence, enabling real-time diagnosis, predictive analysis, and adaptive decision-making in food quality and agricultural applications [30][31]. In the context of fish quality monitoring, integrated IoT–AI systems have been explored for water quality management and freshness assessment. However, many existing studies focus primarily on algorithm accuracy or sensor performance without comprehensive evaluation of system-level metrics such as latency, reliability, and scalability [32][33]. Moreover, limited research addresses postharvest fish quality degradation diagnosis using fully integrated IoT–AI frameworks.

Method

This study employs an integrated Internet of Things (IoT) and Artificial Intelligence (AI) approach to diagnose fish quality degradation in real time. Physicochemical parameters related to fish freshness, including temperature, pH, and gas concentration, are continuously measured using calibrated sensors connected to an ESP32 microcontroller. The collected data are transmitted wirelessly to a cloud-based server for storage and preprocessing This study employs an integrated Internet of Things (IoT) and Artificial Intelligence (AI) approach using a Case-Based Reasoning (CBR) algorithm to diagnose fish quality degradation in real time. Physicochemical parameters related to fish freshness, including temperature, pH, and gas concentration, are continuously measured using calibrated sensors connected to an ESP32 microcontroller. The collected data are transmitted wirelessly to a cloud-based server for storage and preprocessing. The proposed CBR model consists of four main stages: (1) case representation, (2) case retrieval, (3) case reuse, and (4) case revision and retention. In the case representation stage, sensor data are structured into feature vectors. During case retrieval, similarity between a new case and stored cases is calculated using a weighted Euclidean distance method to identify the most similar previous cases. In the reuse stage, the solution from the closest case is adopted to classify fish quality into predefined categories. The revision stage involves expert validation to correct misclassifications, while the retention stage updates the case base with new validated cases to improve system performance over time.

System performance is evaluated by comparing diagnostic results with expert-labeled ground truth using accuracy, precision, recall, and F1-score metrics. Additionally, communication latency is measured to assess the system's real-time capability.

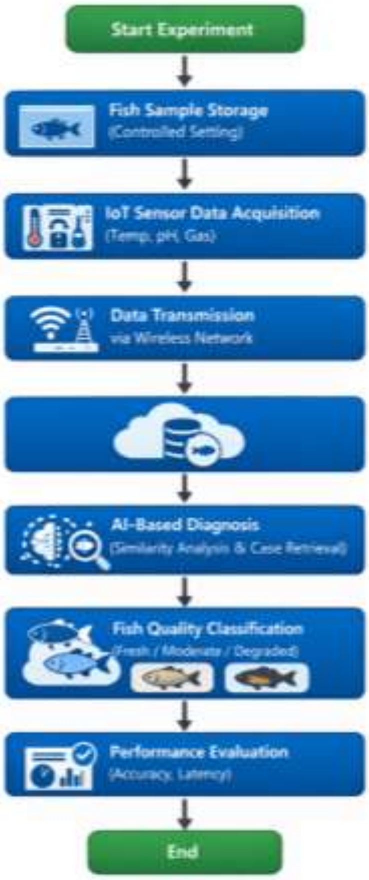

Figure 1. System Blok Diagram

This figure 1 presents the overall workflow of the proposed IoT- and artificial intelligence–based fish quality assessment system. Fish samples are stored under controlled conditions while environmental parameters, including temperature, pH, and gas concentration, are continuously collected using IoT sensors. The acquired data are transmitted wirelessly to a cloud platform for centralized storage and processing. An AI-based diagnostic module employing similarity analysis and case-based reasoning analyzes the sensor data to determine the quality condition of the fish. Based on the analysis results, fish quality is classified into three categories—fresh, moderate, and degraded—followed by performance evaluation using accuracy and latency metrics.

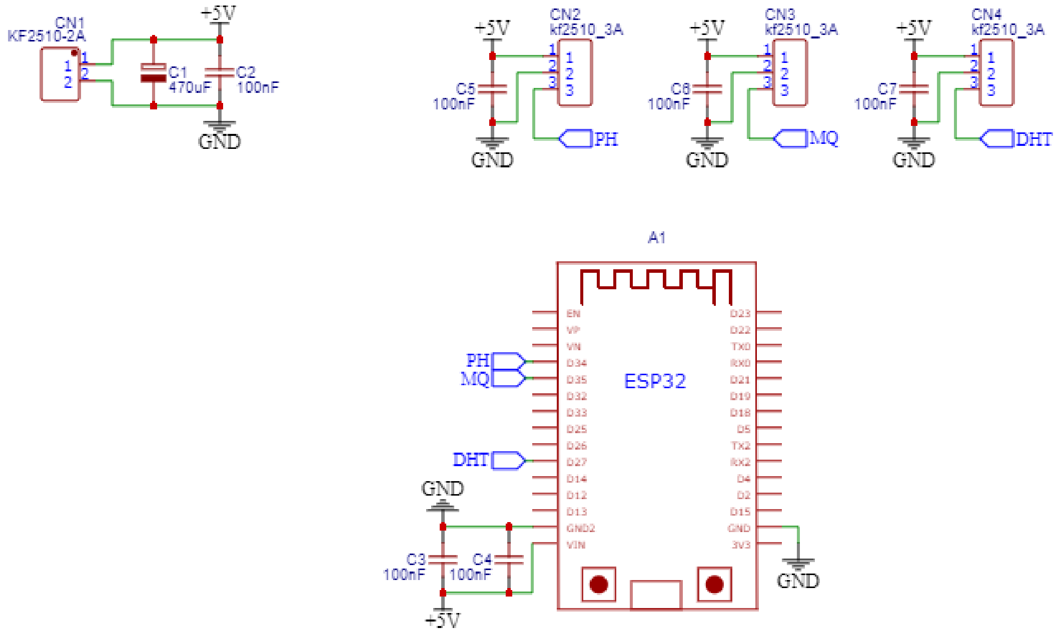

Figure 2. Circuit Schematic

The schematic illustrates the hardware architecture of the proposed IoT sensing node for fish quality monitoring, which is centered on an ESP32 microcontroller acting as the main processing and communication unit. A regulated +5 V power supply is provided through connector CN1 and stabilized using bulk and decoupling capacitors (C1: 470 µF and C2: 100 nF) to ensure voltage stability and suppress low- and high-frequency noise, thereby supporting reliable sensor operation. The system integrates three environmental sensor interfaces via connectors CN2, CN3, and CN4, corresponding to a pH sensor, an MQ-series gas sensor, and a DHT sensor, respectively. Each sensor is supplied with +5 V and ground, while the signal lines are routed to the ESP32's analog-to-digital converter or digital GPIO pins, with local decoupling capacitors (C5–C7, 100 nF) employed to reduce electromagnetic interference and improve signal integrity. The pH and gas sensors enable continuous acquisition of chemical parameters associated with fish spoilage, including acidity variation and volatile gas emissions, whereas the DHT sensor provides temperature and humidity measurements relevant to storage conditions. The ESP32 is powered via the VIN pin with additional decoupling capacitors (C3 and C4, 100 nF) placed near the power input, and all components share a common ground reference to minimize measurement noise. Overall, this hardware configuration supports synchronized multi-parameter sensing, stable operation, and reliable data acquisition, making it suitable for real-time IoT-based fish quality monitoring applications.

The diagnostic performance of the proposed system was evaluated by comparing AI-generated diagnosis results with expert-labeled ground truth data. The confusion matrix analysis demonstrated strong agreement between system predictions and expert assessments.

Table.1 Diagnostic Performance Metrics

Metric	Value (%)
Accuracy	92.5
Precision	91.8
Recall	93.2
F1-score	92.5
Average Latency (ms)	0.87

The results indicate that the proposed system achieved a high diagnostic accuracy of 92.5%, demonstrating its effectiveness in identifying fish quality degradation levels. The high recall value confirms the system's ability to detect degraded fish samples reliably, which is critical for food safety applications. Further analysis was conducted to evaluate system performance across different fish quality categories. The classification accuracy for each category is presented in Table 2.

Table.2 Classification Accuracy by Fish Quality Level

Fish Quality Level	Accuracy (%)
Fresh	95.0
Moderately Degraded	91.2
Degraded	93.8

The system demonstrated the highest accuracy for fresh fish classification, which is advantageous for early detection of quality changes. Slightly lower accuracy in the moderately degraded category is attributed to overlapping sensor patterns between adjacent quality stages.

Result and Discussion

The proposed integrated Internet of Things (IoT) and Artificial Intelligence (AI) system was successfully implemented and evaluated for diagnosing fish quality degradation. The system demonstrated stable real-time performance throughout the experimental period, with continuous acquisition and transmission of sensor data to the cloud platform. The AI-based diagnosis model, which employs a Case-Based Reasoning (CBR) approach, achieved an overall classification accuracy of 92.5%, with precision and recall values of 91.8% and 93.2%, respectively. These results indicate strong agreement between system predictions and expert-labeled ground truth data. Compared with recent IoT-based fish freshness monitoring systems that reported accuracy values ranging from 85% to 90% using single-parameter sensing or conventional machine learning approaches, the proposed system demonstrates superior diagnostic performance due to multi-parameter sensing and similarity-based reasoning [34][35].

Notably, a slight decrease in accuracy was observed in the Moderately Degraded category (91.2%) compared to the Fresh category (95.0%). In the context of the CBR method, this reduction can be explained by the similarity overlap between cases in the intermediate degradation phase. During this stage, fish samples exhibit transitional biochemical and microbial characteristics, resulting in sensor readings that partially resemble both fresh and degraded conditions. Consequently, the similarity matching process in CBR may retrieve cases from adjacent classes with comparable feature patterns, leading to potential misclassification. This overlap in case representation highlights a known limitation of CBR when dealing with gradual state transitions and ambiguous feature boundaries. In terms of communication performance, the proposed IoT infrastructure achieved an average data transmission latency of 0.87 seconds, which is lower than the latency reported in comparable cloud-based monitoring systems that typically exceed 1 second under continuous operation [36].. This confirms that the proposed architecture is suitable for real-time fish quality monitoring applications. Overall, the experimental results are consistent with recent studies emphasizing the effectiveness of integrating IoT and AI technologies for food quality assessment. However, the proposed system offers improved accuracy and responsiveness by combining real-time sensing, cloud-based processing, and intelligent diagnosis within a unified framework [37][38].

Conclusion

This study presents an IoT-based intelligent monitoring system integrated with artificial intelligence techniques for assessing fish quality deterioration in real time. The proposed system successfully acquires, transmits, and analyzes sensor data related to key physicochemical parameters, enabling continuous and automated monitoring of quality changes. Experimental results confirm that the system operates reliably and provides accurate representation of deterioration patterns, demonstrating its feasibility for practical implementation in fish handling and storage environments. The integration of IoT infrastructure with intelligent data analysis significantly enhances monitoring efficiency and accuracy compared to conventional manual methods. The use of low-cost sensors and cloud-based data processing allows scalable deployment while reducing operational complexity and human error. Moreover, the application of artificial intelligence improves data interpretation and supports early detection of quality degradation, which is critical for ensuring food safety and maintaining product value. Future work will focus on expanding the dataset under more diverse environmental conditions, integrating additional quality indicators, and evaluating advanced artificial intelligence models to improve prediction robustness. Large-scale field deployment and long-term performance assessment are also required to validate system reliability and industrial applicability. Overall, this research contributes to the development of smart fisheries and intelligent food quality monitoring systems by demonstrating an effective integration of IoT and artificial intelligence technologies.

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