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FishID+: A Smart Explainable AI and Multi-Sensor IoT Framework for Sustainable Fish Species Identification and Freshness Prediction

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Abstract

The quality and freshness of fish and seafood are crucial factors for ensuring their safety, preventing seafood fraud, and sustainable consumption. The latest achievements in computer vision, Internet of Things (IoT), and artificial intelligence technologies allow for automated evaluation of fish quality. Solutions that can identify fish species and predict its freshness at the point of purchase by end-users remain rare. In this paper, we propose FishID+ – a consumer-oriented and portable solution that incorporates deep learning, multi-sensor IoT, and Explainable Artificial Intelligence (XAI) for real-time fish species identification and freshness prediction. For identifying fish species, our system uses convolutional neural network (CNN) trained on smartphone photos. Our IoT system is based on an ESP32 microcontroller and includes sensors for measuring NH_3 concentration, volatile organic compounds (VOCs), temperature, and humidity. The collected information is classified in a lightweight machine learning algorithm that categorizes the fish into Fresh, Consume Soon, or Spoiled state. Moreover, using SHAP-based explanations, the system identifies which of visual and IoT features have a higher contribution in final decision. The results of prediction, the freshness score, and recommendations are shown through a mobile application, enabling consumers to make informed purchasing decisions without requiring laboratory testing. By integrating species recognition and freshness assessment into a single intelligent platform, FishID+ addresses current limitations in existing seafood monitoring systems. The proposed framework is expected to reduce household food waste, minimize foodborne health risks, enhance consumer confidence, and support sustainable food safety through accessible, explainable, and intelligent IoT technologies.

Keywords: Fish Species Identification; Fish Freshness Prediction; Explainable Artificial Intelligence; Internet of Things; Computer Vision; Edge AI; Multi-Sensor Fusion; Mobile Application; Food Safety; Sustainable Consumption.

1. Introduction

1.1. Background

Fish is a major contributor of nutritious protein to the world. However, because fish spoils easily, freshness is important in terms of food safety and public health. Traditional methods of freshness evaluation, such as sensory inspection, microbiological analysis, and chemical testing, require trained personnel, special equipment, and a lot of time [7], [8]. With the advent of modern technologies such as artificial intelligence (AI), computer vision, and the Internet of Things (IoT), it is now possible to evaluate fish quality in a non-invasive way and quickly using image analysis and gas sensing [1], [5], [11]. As such, CNNs have shown excellent performance in identifying fish species while electronic noses and multi-sensor devices train the right approach to detect volatile compounds related to spoilage [4], [5], [9].

1.2. Problem Statement

There have been many smart fish freshness monitoring systems put forward; however, most of them are applicable in the seafood sector, cold chain industry, laboratories, or fish sellers [1], [5], [11]. Most of these systems make use of very expensive hardware, cloud platform, and special know-how, rendering them unfit for the average consumer in the local market [6], [10]. In addition, much of the existing research is concerned only with the identification of the fish species [9]or its freshness prediction [1], [5], whereas the combination of both features in a consumer-friendly application remains under research. Moreover, the lack of transparency [2] in AI explanation reduces the users' trust in the decision-making process.

1.3. Motivation

When you buy fish you usually look at it. Ask the person selling it if it is fresh. The problem is that this way of doing things is not very good and you can not always trust it [7], [8]. If you pick the kind of fish or buy fish that has gone bad you will lose money and you might get very sick. Now that phones and other small devices are cheap we can make a device that people can carry with them. This device will tell people away if the fish is fresh and what kind of fish it is. The fish freshness device will help people buy fish that's safe to eat [4], [11].

1.4. Research Gap

The assessment of current systems for measuring fish quality, as indicated in the literature shows that the following limitations exist:

•The freshness detecting systems that have been developed using the Internet of Things focus more on industrial or commercial applications rather than on the end-users [1], [6], [11].

•The systems that recognize the fish species [9] and predict the quality are normally established as separate entities and not in a systematic, intelligent method [5], [10].

•The electronic nose technology that is used for measuring the quality does not make use of explainable AI; thus the systems cannot be trusted since they do not provide any insights into the decision-making process [2], [5].

•Applications for consumers that are based on computer vision, the Internet of Things, and explainable machine learning have not been widely developed [4], [11], [13].

Thus, it is evident that on the market there is a lack of integrated, portable, and understandable solution that can help users to assess the fish quality and identify its species right away.

1.5. Objectives

The aims of this study are:

(1) To create a deep learning model that can identify fish species from pictures taken by a smartphone [4], [9].

(2) To establish a portable multi-sensor device for determining whether fish is fresh or not [1], [5], [11].

(3) To connect computer vision and sensor information in order to correctly predict the freshness [3], [4].

(4) To utilize Explainable AI (SHAP) to obtain clear information about the prediction [2].

(5) To create an application that will tell about the fish species, the freshness of the fish, and suggest to the user where to buy it from [13].

1.6. Contributions

The main findings of this study are:

- An original FishID+ framework that integrates the identification of fish species and prediction of freshness in one intelligent platform [4], [9].
- An IoT device that is portable and consumer-friendly, which is based on ESP32 technology and a variety of environmental sensors for non-destructive evaluation of fish quality [1], [5], [11].
- A hybrid artificial intelligence framework that uses deep learning and machine learning technologies for the identification of fish species and the prediction of freshness [3], [4]. ‘
- Using Explainable AI (SHAP) for transparency and increasing consumer confidence regarding the product [2].
- A decision-support application that operates on a smartphone for consumers’ verification of fish quality before purchase [13].
- An eco-friendly solution that enhances safety in food and raises customers’ awareness while minimizing food waste at home [8], [10].

2. Literature Review

2.1. Fish Species Recognition Using Convolutional Neural Networks (CNNs)

The recognition of fish species by machine has gained public interest thanks to its potential for use in the management of fisheries, seafood authentication, and conservation of biodiversity. Traditional image processing techniques depended on manually developed features such as color, texture, and shape. However, these approaches tend to be impacted by changes in lighting, background, or fish orientation. Technological advances in the area of deep learning have made it possible for CNNs to learn powerful visual features from pictures of fish automatically[9].

Well-designed light-weight networks such as MobileNet or EfficientNet [4]proved to be highly efficient in fish identification applications whereas more complex models such as ResNet and Vision Transformers succeeded too[9].

As emphasized by the latest reviews, the trend in the industry is that more and more mobile fish species identification systems are being developed with the use of edge AI technologies and smartphone capabilities.

Nevertheless, even though machine-learning technologies have improved significantly in this field, the majority of CNN-based studies do not pay attention to the decomposition of the problem into two parts (species recognition and freshness analysis). Hence, to date potential customers do not have a system that would combine the capability of species[9], [13].

2.2. IoT-Based Fish Freshness Detection

IoT is a viable technology for monitoring fish quality through continuous detection of environmental and spoilage parameters. Current IoT technologies utilize sensors for measuring ammonia (NH_3), volatile organic compounds (VOCs), temperature, humidity, and various other freshness parameters. The signals from the sensors are sent through wireless communication systems to the cloud or edge platforms, where machine learning algorithms come into play to assess the freshness of fish. Such technologies allow minimizing the need for laboratory tests and enable real-time monitoring of the seafood during its storage and transportation [1], [5], [11].

Nevertheless, most of the existing IoT-based solutions for monitoring freshness are developed for cold-chain logistics, seafood processing, and retail warehouses and not for individual users[8], [11] [1], [6].

2.3. Electronic Nose Systems

Electronic Nose (E-Nose) technology has become one of the widely used non-destructive techniques for checking fish freshness. These systems have gas sensors that can detect gases linked to spoilage such as ammonia, trimethylamine (TMA) and volatile organic compounds that come out when bacteria break down the fish. Machine learning algorithms like Support Vector Machines (SVM) Artificial Neural Networks (ANN) Random Forest and XGBoost have been used successfully to classify fish freshness using the signals from the sensors. Some studies have shown accuracy when combining electronic nose systems with IoT platforms to keep track of freshness all the time [3] [5].

Even though electronic noses offer non-destructive ways to check freshness they are mostly used in labs or factories. Their high cost, need for calibration and not being easy for regular people to use stop them from being used more widely by people who buy fish. The technology of the Electronic Nose (E-Nose) has become popular as a non-destructive method used for checking fish freshness. In short E-Nose systems have gas sensors to detect spoilage gases like ammonia, trimethylamine (TMA) and other volatile organic compounds that show up during the breakdown by bacteria. Other methods used include,. Are not limited to, machine-learning algorithms like Support Vector Machines (SVM) Artificial Neural Network (ANN) Random Forest and XGBoost[3], [5], [11] which have been helpful in sorting out fish freshness based on what the sensors pick up. Most designs, for noses show strong prediction power as shown in various studies where E-Nose was used with IoT [5], [11].

Even though the electronic nose is known for non-destructive freshness checks it is mainly used for lab or business purposes[1], [5].

2.4. Explainable AI in Food Quality Assessment

The improvement of food quality determination has been made possible by advancements in Artificial Intelligence. The downside, however, is certain deep learning algorithms function as "black boxes," rendering their predictions almost impossible to interpret.

This is where Explainable Artificial Intelligence (XAI) comes in. Methods such as SHAP, LIME, Grad-CAM, and attention visualization have emerged to fight the lack of transparency in food quality prediction. The key idea of this approach is to understand the role of image features and sensor data in the classification decisions. [2].

As the literature suggests, these approaches have already been utilized in the process of fish freshness implementation in image-based deep learning models. However, the combination of Explainable AI with a multi sensor IoT approach, species recognition, and consumer mobile applications is still unexplored[2], [10].

2.5. Research Gap Analysis

Reference	Technique	Application	Limitations	Gap Addressed by FishID+
Qin et al. [9]	Computer Vision, CNN	Fish freshness monitoring	Image-based only; no IoT integration	Integrates computer vision with multi-sensor IoT.
Yildiz et al. (2024) [13]	CNN + Mobile Application	Fish-eye freshness detection	Freshness only; no species identification	Combines species identification and freshness prediction.
Madhubhashini et al. (2024) [10]	Computer Vision, E-Nose, E-Tongue	Fish freshness review	Highlights need for consumer applications	Consumer-centric portable IoT framework.
Suzhang et al. (2026) [12]	S-CNN	Fish freshness classification	Uses only eye and gill images	Fuses visual features with gas sensor data.
Dharmaraj & Jacab (2026)	Explainable AI Review	Fish quality assessment	Review only; no integrated implementation	Real-time XAI-enabled mobile decision-support system.

3. Methodology

3.1. System Architecture

The FishID+ framework is a consumer-focused smart system that incorporates computer vision, multi-sensor IoT, edge AI, and XAI to accomplish fish species detection and freshness prediction at the same time. The framework includes four modules: (i) fish image capturing and species detection, (ii) multi-sensor data capturing, (iii) freshness prediction based on edge AI and (iv) decision-making on a mobile phone. Countless existing multimodal frameworks have been proven able to increase accuracy in food quality assessment by incorporating both visual information and sensor inputs [1], [8], [10].

In the beginning, the consumer takes a photograph of a fish using a special mobile application. All this time, a portable IoT device measuring ammonia (NH_3), volatile organic compound (VOC), temperature, and humidity is present and conducting measurements of environmental factors that influence spoilage [1], [5], [11]. The taken image goes through a CNN engine for fish species detection [4], [9], whereas the data from sensors are examined by a machine learning classifier [3]. Once predictions are made, the results are sent to a smartphone using Bluetooth or Wi-Fi, and SHAP-based clarifications are made available [2].

3.2. Hardware Components

The proposed prototype consists of inexpensive and portable hardware components suitable for consumer use.

Component	Purpose
ESP32 Development Board	Edge AI processing and wireless communication
MQ-137	Ammonia (NH_3) detection
MQ-135	VOC detection
DHT22	Temperature and humidity measurement
ESP32-CAM / Smartphone Camera	Image acquisition
Bluetooth/Wi-Fi	Mobile communication

The ESP32 platform was selected because of its low power consumption, integrated wireless connectivity, and suitability for embedded AI applications [4]. MQ-series gas sensors have been widely adopted in electronic nose systems for detecting spoilage gases released during fish decomposition [1], [5].

3.3. Mobile Application

A certain mobile application has been designed in such a way that it can provide decision support to prosumers. The application takes images of fish, is in communication with the IoT device, showing the identified fish species, and also indicating the freshness score, freshness category, SHAP explanation, and proposal for purchase.

Using the smartphone as a means for assessing food quality has just become a method that helps to reach a greater level of availability and makes the consumer more aware of what is going on in the field of gastronomic industry [11], [13].

3.4. Dataset

The proposed framework employs two datasets.

3.4.1. Fish Species Dataset

Fish species identification is trained using publicly available datasets such as Fish4Knowledge, DeepFish, and the Kaggle Fish Species Dataset, which contain images of commercially important species including sardine, mackerel, tuna, pomfret, anchovy, and seer fish. These datasets have been widely used for CNN-based fish classification research [9].

3.4.2. Freshness Dataset

The freshness prediction model utilises multi-sensor measurements consisting of:

- NH_3 concentration
- VOC concentration
- Temperature
- Relative Humidity

Each sample is labelled as:

- Fresh
- Consume Soon
- Spoiled

Recent studies have shown that ammonia and VOC concentration strongly correlate with microbial spoilage and fish freshness [1], [5], [8], [11].

3.5. CNN for Fish Species Identification

Fish species recognition is performed using MobileNetV3, a lightweight convolutional neural network specifically designed for mobile and embedded devices. MobileNetV3 achieves high classification accuracy while significantly reducing computational complexity, making it suitable for smartphone deployment [4].

Before classification, captured images undergo preprocessing, including image resizing (224 × 224 pixels), normalization, and data augmentation through rotation, horizontal flipping, and brightness adjustment to improve model generalisation [4], [9].

3.6. Multi-Sensor IoT for Freshness Prediction

The IoT module continuously measures spoilage-related environmental parameters using multiple sensors. The selected parameters include ammonia (NH_3), volatile organic compounds (VOCs), ambient temperature, and relative humidity, which collectively form a Digital Freshness Fingerprint representing the quality of the fish.

The feature vector is expressed as

F=[NH3,VOC,T,RH]F=[NH_3,VOC,T,RH]F=[NH3,VOC,T,RH]

where NH_3 denotes ammonia concentration, VOC represents volatile organic compounds, T is ambient temperature, and RH represents relative humidity.

Previous studies have demonstrated that combining multiple environmental parameters improves freshness prediction compared with single-sensor approaches [1], [5], [11].

3.7. Edge AI

Unlike conventional cloud-based monitoring systems, FishID+ performs freshness prediction directly on the ESP32 microcontroller using a lightweight Random Forest classifier. Random Forest was selected due to its high prediction accuracy, robustness to noisy sensor data, low computational complexity, and suitability for embedded applications [3].

Edge AI reduces prediction latency, minimizes communication costs, improves user privacy, and enables offline operation, making it particularly suitable for consumer-oriented applications [4], [11].

3.8. Explainable AI (SHAP)

To improve transparency and user trust, FishID+ integrates SHapley Additive exPlanations (SHAP) to interpret freshness predictions. SHAP calculates the contribution of each sensor feature towards the final classification, enabling users to understand why a fish is classified as Fresh, Consume Soon, or Spoiled [2].

Explainable AI has recently gained significant attention in food quality assessment because it improves model interpretability and supports reliable AI-assisted decision-making [2], [10].

3.9. Proposed Algorithm

The proposed FishID+ algorithm consists of the following steps:

1. Capture fish image using the smartphone.
2. Acquire NH_3, VOC, temperature, and humidity measurements.
3. Preprocess the captured image.
4. Identify fish species using MobileNetV3.
5. Generate the Digital Freshness Fingerprint.
6. Predict freshness using the Random Forest classifier.
7. Compute SHAP feature importance values.
8. Display species name, freshness score, freshness category, and purchasing recommendation in the mobile application.

The workflow integrates computer vision, IoT sensing, edge AI, and explainable machine learning into a unified consumer-oriented framework [1], [4], [11].

3.10. Flowchart

Start → Capture Fish Image → Acquire Sensor Data (NH_3, VOC, Temperature, Humidity) → Image Preprocessing → MobileNetV3 Species Identification → Generate Digital Freshness Fingerprint → Random Forest Freshness Prediction → SHAP Explanation → Display Results in Mobile App → End

4. Proposed Framework Validation (Expected Outcomes)

4.1. Expected Performance

The FishID+ framework is going to make it easy for people to figure out what kind of fish they have and how fresh it is. This is because the FishID+ framework uses computer vision and special sensors that are connected to the internet. It also uses something called artificial intelligence and Explainable Artificial Intelligence.

Some studies have shown that certain kinds of networks like MobileNetV3 are really good at identifying things and do not need a lot of power to work. This makes them perfect for use in smartphones and other small devices[4], [9]. There are also electronic nose systems that can detect when fish has gone bad by smelling the air around it[1], [5], [11].

The FishID+ framework is different from ways of doing things because it looks at what the fish looks like and what is going on around it at the same time. This means it can make decisions about what kind of fish it is and how fresh it is. The FishID+ framework is going to be more reliable than ways of doing things because it uses more, than one kind of information. This is important because other ways of doing things only look at one thing at a time and that can be limiting. The FishID+ framework is better because it combines all the information it has into one system[1], [8], [10].

4.2. Expected Advantages of the Proposed Framework

The proposed FishID+ framework offers several advantages over conventional fish freshness assessment systems.

•Consumer-Oriented Decision Support: Unlike laboratory-based or industrial monitoring systems, FishID+ is specifically designed for ordinary consumers purchasing fish in local markets, enabling instant freshness assessment through a smartphone application [13].

•Integrated Species Identification and Freshness Prediction: Existing studies generally focus either on fish species classification or freshness detection. FishID+ combines both functionalities into a single intelligent platform, providing comprehensive information for purchasing decisions [9], [13].

•Portable Multi-Sensor IoT Device: The integration of ammonia (NH_3), VOC, temperature, and humidity sensors enables non-destructive freshness assessment using a compact ESP32-based device suitable for real-time operation [1], [5], [11].

•Explainable Artificial Intelligence: The incorporation of SHAP provides transparent explanations of prediction results by identifying the contribution of each sensor feature and image characteristic. This improves user confidence and supports trustworthy AI-based decision making [2].

•Edge AI Processing: Deploying the machine learning model directly on the ESP32 microcontroller reduces network dependency, minimizes latency, enhances privacy, and enables offline operation in locations with limited internet connectivity [3], [4].

•Contribution to Sustainable Development: By reducing food waste, preventing the purchase of spoiled seafood, and increasing consumer awareness, the proposed framework supports sustainable food safety and responsible consumption, aligning with the United Nations Sustainable Development Goals (SDGs) [7], [8], [10].

4.3. Future Validation Plan

The FishID+ framework that is being proposed will be tested in work through building a prototype and testing it in real situations.

4.4. Dataset Validation

The model that identifies fish species will be. Checked using public datasets like Fish4Knowledge, DeepFish and the Kaggle Fish Species Dataset. These datasets have images of fish that're important for business [9].

The model that predicts how fresh the fish is will be made using data from sensors. This data comes from fish that're fresh, a little spoiled and very spoiled. The testing is done in a controlled setting. The data from the sensors will include how much ammonia is there how much VOC is there the temperature around the fish and how humid the air's. This follows ways that were used in studies about how fresh fish is [1], [5], [8], [11].

4.5. Performance Evaluation

The framework that is being proposed will be checked using ways to see how well machine learning models work. These ways include:

- Classification Accuracy
- Precision
- Recall
- F1-score
- Specificity
- ROC-AUC
- Response Time
- Mobile Application Latency
- Edge AI Inference Time

The results that are found will be compared with ways of doing machine learning like Support Vector Machine (SVM) K-Nearest Neighbour (KNN) Artificial Neural Networks (ANN) Random Forest and other ways that use CNN [3], [9], [12], [13].

4.6. Prototype Validation

A small device that can be carried around will be made. This device will have an ESP32 microcontroller, a MQ-137 ammonia sensor, a MQ-135 VOC sensor, a DHT22 temperature and humidity sensor and a smartphone app. This device will be used to check how well the system works in fish markets. People will also give their thoughts, about how easy to use the system's how clear the predictions are and how confident they feel about buying the fish [1], [5], [13].

4.7. Expected Research Contributions

1. The FishID+ system is going to do a lot of things.
2. It will help us make a way to figure out what kind of fish we have and how fresh it is at the same time.
3. We will make a new system that helps people who buy seafood make choices.
4. The FishID+ system will use something called Explainable Artificial Intelligence, which is also known as SHAP to tell us why it thinks the fish is fresh or not. This will help people trust the system more.
5. We will show that we can use a kind of intelligence called Edge AI to check the quality of food in real time using small and affordable computers.
6. The FishID+ system will help stop people from selling seafood prevent people from getting sick, from bad food reduce the amount of food that people throw away and help people make better choices when they buy seafood.

Figure 4. Expected Validation Framework

Fish Image + Sensor Data

↓

Fish Species Identification
(MobileNetV3 CNN)

↓

Multi-Sensor IoT Data
(NH_3, VOC, Temperature, Humidity)

↓

Edge AI Freshness Prediction (Random Forest)

↓

SHAP Explainability

↓

Smartphone Application

↓

Species + Freshness Score + Purchase
Recommendation + Feature Explanation

5. Discussion

The FishID+ framework is a way to help people identify fish species and check how fresh the fish is. It uses computer vision, special sensors and artificial intelligence to make it easier for consumers to make choices when they buy fish. This is different from systems that mostly help people who sell fish or work in labs. The FishID+ framework is made for people who buy fish to eat.

When you use FishID+ you get information than you would if you just looked at the fish or used a special gas sensor. The computer vision part of the system can identify the type of fish by looking at its outside. The special sensors can detect smells like ammonia that you cannot see. By combining these two types of information the system can make predictions about how fresh the fish is.

One of the things about FishID+ is that it can explain why it made a certain prediction. Most other systems just give you an answer without telling you why. FishID+ gives you scores that show how important different things are, like how much ammonia's in the air or what the temperature is. This makes the system more transparent. Helps people trust it more.

The FishID+ system also works on a computer called an ESP32 microcontroller. This is good because it means the system can work even when it is not connected to the internet. It is also faster and more private, which makes it good for use in fish markets or supermarkets.

There are still some challenges to overcome. The system needs a lot of data to work well. It can be affected by things like the type of fish or how it is stored. The sensors can also get less accurate over time. The lighting can affect how well the system works. To make the system better we need to test it in different places and add more sensors to make it more accurate.

The FishID+ framework is a tool for people who want to know more about the fish they buy. The FishID+ system can help people make choices and eat fresher fish. The FishID+ framework is a step forward, in helping people identify fish species and check how fresh the fish is.

6. Conclusion

This paper introduced FishID+ a system that puts the consumer first. It combines identifying fish species and predicting how fresh they are. The system uses computer vision sensors connected to the internet computers that work close to the data and ways to explain how the artificial intelligence works. Most other systems for checking how fresh fish is focus on factories, labs or keeping fish cold during transport. FishID+ helps people check how good the fish is before they buy it. They can use a device that connects to the internet and a phone app. The system uses computer networks to find out what kind of fish it is, checks the environment does smart calculations right there and gives clear reasons for its answers. This makes it easy for people to make choices. The system could help make food safer cut down on waste at home stop seafood and make people trust buying fish more. Also because it uses smart computers it can work in places where there is no steady internet like local fish markets. In the future they want to make a working model that works in time gather a big collection of different types of information test the system in many different places and add ways to find dangerous chemicals in the fish and predict how long it will stay fresh. The FishID+ system is a step, toward better ways to check food quality. It uses internet of things ways to explain things and phones to make sure food is safe and lasts longer.

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Conflict of Interest

We declare no conflict of interest.

Data Availability Statement

No new datasets were generated or analysed during this study. The proposed framework is conceptual in nature. Future work will utilize publicly available datasets, including Fish4Knowledge, DeepFish, and other benchmark fish image datasets, together with sensor data collected during prototype development..

Author Contributions

Conceptualization, L.T.; methodology, L.T.; literature review, S.V.; investigation, S.V; writing—original draft preparation, L.T.; writing—review and editing, S.V.; visualization, L.T.

References

[1] L. Franceschelli, A. Berardinelli, S. Dabbou, L. Ragni, and M. Tartagni, "Sensing Technology for Fish Freshness and Safety: A Review," Sensors, vol. 21, no. 4, Art. no. 1373, 2021, doi: 10.3390/s21041373.

[2] S. M. Lundberg and S.-I. Lee, "A Unified Approach to Interpreting Model Predictions," in Advances in Neural Information Processing Systems (NeurIPS), vol. 30, 2017.

[3] L. Breiman, "Random Forests," Machine Learning, vol. 45, no. 1, pp. 5–32, 2001, doi: 10.1023/A:1010933404324.

[4] A. Howard, M. Sandler, G. Chu, L.-C. Chen, B. Chen, M. Tan, W. Wang, Y. Zhu, R. Pang, V. Vasudevan, Q. V. Le, and H. Adam, "Searching for MobileNetV3," in Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), 2019, pp. 1314–1324.

[5] S. Grassi, G. Benedetti, L. Opizzio, M. Di Nardo, and A. Buratti, "Meat and Fish Freshness Assessment by a Portable and Simplified Electronic Nose System (Mastersense)," Sensors, vol. 19, no. 14, Art. no. 3225, 2019, doi: 10.3390/s19143225.

[6] A. Pratiwy, Aisyah, and Y. Mulyani, "Digitization in Detecting Fish Freshness Quality: Literature Review," Asian Journal of Fisheries and Aquatic Research, vol. 15, no. 6, pp. 141–147, 2021, doi: 10.9734/AJFAR/2021/v15i630359.

[7] A. Ghaly, D. Dave, S. Budge, and M. Brooks, "Fish Spoilage Mechanisms and Preservation Techniques: Review," American Journal of Applied Sciences, vol. 7, no. 7, pp. 859–877, 2010, doi: 10.3844/ajassp.2010.859.877.

[8] P. V. Viji, V. T. Tanuja, G. Ninan, K. A. Lalitha, and C. K. Binsi, "A Comprehensive Review on Freshness of Fish and Assessment: Analytical Methods and Recent Innovations," Food Research International, vol. 133, Art. no. 109157, 2020, doi: 10.1016/j.foodres.2020.109157.

[9] J. Qin, X. Wang, Y. Li, and H. Zhang, "Fish Species Classification Based on Deep Convolutional Neural Networks," Ecological Informatics, vol. 75, Art. no. 102040, 2023.

[10] K. Madhubhashini et al., "Current Applications and Future Trends of Artificial Senses in Fish Freshness Determination: A Review," Journal of Food Science, vol. 89, no. 9, 2024.

[11] Y. Zhang et al., "Evaluation of IoT-Enabled Monitoring and Electronic Nose Spoilage Detection for Salmon Freshness During Cold Storage," Foods, vol. 9, no. 11, Art. no. 1579, 2020.

[12] B. Suzhang, X. He, X. Xu, X. Huang, L. Qin, and S. Gao, "S-CNN: A Dual-Region Feature Convolutional Network for Fish Freshness Assessment Based on Eyes and Gills Characteristics," Expert Systems, vol. 43, no. 7, Art. no. e70319, 2026, doi: 10.1111/exsy.70319.

[13] M. B. Yildiz, E. T. Yasin, and M. Koklu, "Fisheye Freshness Detection Using Common Deep Learning Algorithms and Machine Learning Methods with a Developed Mobile Application," European Food Research and Technology, vol. 250, no. 7, pp. 1919–1932, 2024.

[14] M. G. Lanjewar and K. G. Panchbhai, “Enhancing Fish Freshness Prediction Using NASNet-LSTM,” Journal of Food Composition and Analysis, vol. 127, Art. no. 105945, 2024.

[15] G. Wang, H. He, J. Xu, et al., “Preparation of Fish Freshness Colorimetric Indicator Label Based on the Dye of BTB Grafted on MOF Carrier,” Sensors and Actuators B: Chemical, vol. 354, Art. no. 131230, 2022.

[16] X. Yu, L. Tang, X. Wu, and H. Lu, “Nondestructive Freshness Discriminating of Shrimp Using Visible/Near-Infrared Hyperspectral Imaging Technique and Deep Learning Algorithm,” Food Analytical Methods, vol. 11, no. 3, pp. 768–780, 2018.