BIMA
BULLETIN OF INTELLIGENT MACHINES AND ALGORITHMS
Vol. 1 No. 5 July 2026
E-ISSN: 3132-5115
DOI: 10.65780/bima.v1i5.32

Intelligent Cold Chain Control System Based on Data Fusion for Refrigerated Truck Fleets

Luckman Hasannudin[1]*, Very Kurnia Bakti[2], Abdul Basit[3]

Computer Engineering[1]
Universitas Harkat Negeri Tegal, Tegal, Indonesia[1]
https://harkatnegeri.ac.id/[1]
luckmanhasannudin29@gmail.com[1], verykurniabakti@gmail.com[2], abdulbasit@uhn.ac.id[3]

Abstract. As a maritime nation, Indonesia holds substantial marine-resource potential, yet its distribution faces serious challenges because fishery commodities are highly perishable and prone to rapid quality decline. Failure to maintain consistent temperatures throughout the cold chain frequently causes significant economic losses for business operators. This study aims to design and build an Intelligent Cold Chain Control System Based on Data Fusion for Refrigerated Truck Fleets using an ESP32-S3 microcontroller. The system integrates Internet of Things (IoT) technology with a data fusion technique that combines readings from an RTD PT100 temperature sensor paired with a MAX31865 module, an MPU6050 vibration sensor, and a NEO-8M GPS module for real-time location tracking, using an SD card as a buffer medium and the MQTT protocol for transmitting data to a server. The research method applied is the Prototype method, comprising requirements analysis, initial system design, prototype development, user evaluation, prototype improvement, prototype testing, and implementation. Data were collected through field observation, interviews, and a literature study at CV. Mutiara Samudera Indonesia, Tegal. Test results show that the PT100 sensor was able to read temperatures down to −15.5°C with a deviation of only 0.2°C against a reference instrument, the NEO-8M GPS module successfully displayed location coordinates within a tolerance of a few meters compared with Google Maps, and the MPU6050 sensor was able to detect vibration changes on three axes in a stable manner. This prototype is expected to support quality monitoring and distribution efficiency for marine commodities carried by refrigerated truck fleets.

Key words: Cold Chain; Data Fusion; ESP32-S3; Refrigerated Truck

1. INTRODUCTION

Indonesia is the world's largest archipelagic nation, with a coastline exceeding 81,000 km and a marine territory covering more than 3.25 million km^2 [1], giving it substantial potential as a driver of national economic growth. Logistics, however, remains a serious obstacle in the distribution of goods between regions [2], particularly for marine products that are highly perishable and vulnerable to post-harvest quality degradation. Persistent gaps between global cold chain monitoring best practice and on-the-ground operating conditions in developing supply chains have been widely documented, with fluctuations most pronounced during the last-mile delivery stage [3]. Cold chain standards generally set refrigeration temperatures in the range of 0–10°C and freezing below −18°C [4], yet field implementation still frequently experiences temperature deviations at this stage, making commodities such as squid — which possess high endogenous enzyme activity — highly susceptible to premature spoilage [5].

To address this problem, a prototype Internet of Things (IoT)-based refrigeration control system capable of real-time temperature monitoring was developed around an ESP32-S3 microcontroller, following the same rationale that has driven recent IoT temperature-recorder designs for perishable marine cargo [6]. The ESP32-S3 was selected for its dual-core processing capability, integrated wireless connectivity, and support for external PSRAM, which assists in handling multi-sensor data fusion workloads, consistent with prior ESP32-based remote monitoring and control implementations [7]. The temperature sensor used is an RTD PT100 combined with a MAX31865 module, chosen for its high stability, resistance to chemical corrosion, and its ability to operate across a wide range in accordance with the IEC 60751 standard. In addition, an MPU6050 accelerometer-gyroscope sensor is used to detect vibration and shock during distribution, while a NEO-8M GPS module — following the positioning approach used in comparable IoT vehicle-tracking work [8] — is used for real-time vehicle location tracking. These three data sources are combined using a data fusion technique, an approach

Vol. 1 No. 5 July 2026
E-ISSN: 3132-5115
DOI: 10.65780/bima.v1i5.32

whose value for reconciling heterogeneous sensor streams into a single, more reliable picture of supply-chain conditions has been established in the wider food-logistics literature [9], so that monitoring of cargo environmental conditions can be carried out more comprehensively. This enables automated alerts to be sent to fleet operators via smartphone or cloud-based systems whenever temperature or vibration parameters exceed predetermined thresholds.

2. LITERATURE REVIEW

Several prior studies provide the foundation for this research. An IoT-based environmental monitoring system built around an ESP32 microcontroller and a Firebase real-time database demonstrated stable, consistent communication between the sensor hardware and the cloud platform, supporting continuous remote monitoring with minimal manual intervention [10]. A comparative study of power efficiency and latency between the ESP32 and the Raspberry Pi Pico W found that the Pico W was more power-efficient (90 mA) and had a faster boot time (950 ms), while the ESP32 offered superior real-time latency (240 ms) [11]. An IoT- and Artificial Neural Network (ANN)-based cold-storage monitoring system reported a testing accuracy of up to 99% with an error rate below 1% [12], demonstrating the potential of combining IoT sensing with machine-learning classification. On the mechanical side, computational work on airflow and heat transfer inside refrigerated truck bodies has shown that loading configuration strongly affects internal temperature uniformity [13], a finding echoed by controlled measurements of temperature distribution under different box-loading patterns in refrigerated trucks [14]. Beyond sensing hardware, broader supply-chain studies emphasize that emerging digital technologies improve traceability and visibility specifically within fishery cold chains [15], and that non-destructive evaluation techniques are increasingly used alongside conventional sensors to assess seafood quality throughout cold chain logistics [16]. At the architectural level, information-systems research on value-centric IoT design for food supply chains has framed sensor portfolio selection and information fusion as a joint design problem rather than a matter of adding sensors independently [9], while sensor-network research on perishable food supply chains has likewise argued for integrated sensing, communication, and control rather than isolated point measurements [17]. Recent work on AI-IoT synergy for cold chain logistics [18] and systematic reviews of IoT-based environmental monitoring for logistics [19] reinforce that the field is moving toward multi-sensor, multi-parameter monitoring rather than single-variable temperature logging alone. These studies collectively validate the use of the ESP32 microcontroller family together with temperature, vibration, and positioning sensors to support marine-product distribution, and they also make clear that a genuinely comprehensive cold chain monitoring system needs to combine — rather than merely collect — data from more than one sensing modality; this is precisely the gap that the present data fusion-based prototype is designed to close.

The cold chain is an integrated system of methods for maintaining a continuously low temperature for perishable commodities, from production through to final consumption. Refrigerated truck fleets are the principal link in this distribution chain, yet they are often the weakest point because of the risk of a broken cold chain during loading, unloading, or refrigeration equipment malfunction. Data fusion is a technique for combining information from multiple heterogeneous sensor types to produce a more accurate and reliable understanding of system status than reliance on a single sensor alone. The hardware architecture of this system uses the ESP32-S3 microcontroller as the main processing unit because of its dual-core Xtensa LX7 processor running at up to 240 MHz, 2.4 GHz Wi-Fi and Bluetooth Low Energy 5.0 connectivity, and support for USB OTG and additional memory. The MPU6050 sensor combines a three-axis accelerometer and gyroscope (6 DOF) that communicates over I2C to detect vibration and movement. The RTD PT100 temperature sensor operates based on the change in resistance with temperature and is paired with a MAX31865 module that converts the analog resistance signal into digital data. The NEO-8M GPS module determines location coordinates from GNSS satellite signals via serial UART communication. An SD card module serves as a temporary data-buffer medium when the internet connection is interrupted, an XY3606 step-down module reduces and stabilizes the voltage, and an 18650 lithium battery is used as the system's main power source.

3. METHODS

The method applied in this study is the Prototype method, consisting of seven stages: requirements analysis, initial system design, prototype development, user evaluation, prototype improvement, prototype testing, and implementation. This method was chosen because it supports incremental system development, allows for direct testing, and facilitates rapid correction whenever errors are found during development.

This research was conducted at CV. Mutiara Samudera Indonesia (MSI), Jl. Bali No. 34, Mintaragen, Tegal Timur, Tegal City, Central Java, a company engaged in fishery-product processing and distribution, making it directly relevant to the focus of this research.

The overall research workflow is illustrated in Fig. 1. The process starts with requirements analysis based on field observation and literature review, proceeds through iterative prototype design, development, and user evaluation, and concludes with implementation once the prototype passes testing. If testing reveals a shortcoming, the workflow loops back to the prototype-improvement stage before testing is repeated, ensuring that the final

Vol. 1 No. 5 July 2026
E-ISSN: 3132-5115
DOI: 10.65780/bima.v1i5.32

system meets the functional and reliability requirements identified at the outset.

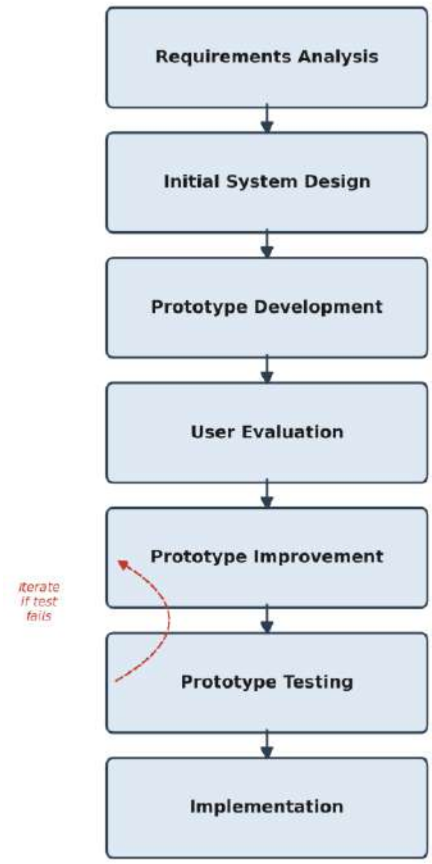

Fig.1. Research workflow of the Prototype development method.

Research began with requirements analysis through a literature study and field observation to identify problems in the distribution of marine products using refrigerated trucks. This was followed by an initial system design in the form of a block diagram showing the relationship between the ESP32-S3 microcontroller and the PT100/MAX31865 temperature sensor, the MPU6050 vibration sensor, the GPS module, the RTC module, and the data-storage medium. The prototype was then built by assembling all hardware components and programming the microcontroller to read, process, store, and display sensor data. The completed prototype was tested by users to assess its performance in monitoring temperature, vibration, and vehicle location; the results of this evaluation formed the basis for improvements to both the hardware and the software. After these improvements, the prototype was retested to confirm system stability before entering the final implementation stage, in which all monitoring functions for temperature, vibration, and vehicle location were run under real operating conditions.

In addition to the literature study, primary data were collected through direct observation and interviews. Observation was carried out at the marine-product distributor's site to examine operational conditions in detail, and it showed that temperature and shipment-condition monitoring were still limited and were not yet conducted in real time. Interviews were held with the management of CV. Mutiara Samudera Indonesia to explore the challenges faced during distribution, including the types of marine products distributed, current temperature-monitoring practices, difficulties in maintaining temperature stability, and the need for a technology-based monitoring system capable of tracking temperature, vibration, and vehicle location in real time. The research was carried out at CV. Mutiara Samudera Indonesia, located at Jl. Bali No. 34, Mintaragen, Tegal Timur, Tegal City, Central Java, over a period of 150 days from January to March 2026; the first month was used for proposal preparation and initial data collection and processing, the second month for model design and training, and the third month for evaluation, model deployment, and report completion.

4. RESULTS AND DISCUSSION

This section explains the results of implementing the intelligent cold chain control prototype together with a discussion of the test results for each component, in order to determine whether the prototype functions in accordance with the planning specifications that were established.

4.1. System architecture and implementation.

The monitoring system for refrigerated trucks was implemented as a prototype based on the ESP32-S3 microcontroller, connected to a PT100/MAX31865 temperature sensor, an MPU6050 vibration sensor, a NEO-8M GPS module, an SD card module as a storage buffer, an XY3606 step-down module, and an 18650 lithium battery as the power source. The architecture of these connections is summarized in the block diagram in Fig. 2.

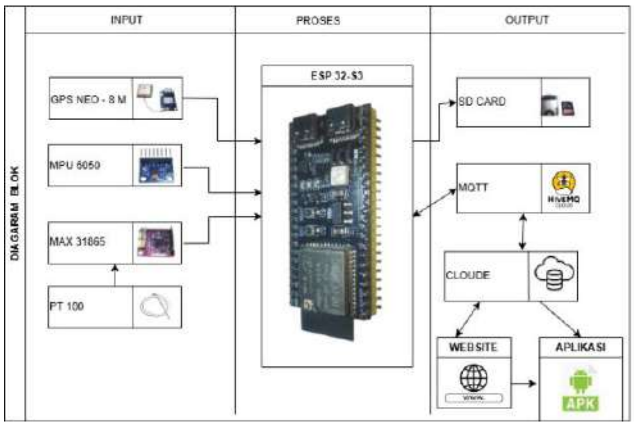

Fig. 2. System architecture block diagram of the refrigerated truck monitoring prototype.

BIMA
BULLETIN OF INTELLIGENT MACHINES AND ALGORITHMS
Vol. 1 No. 5 July 2026
E-ISSN: 3132-5115
DOI: 10.65780/bima.v1i5.32

All components were first assembled on a breadboard, as shown in Fig. 3, to simplify the testing process before the circuit was migrated to a printed circuit board.

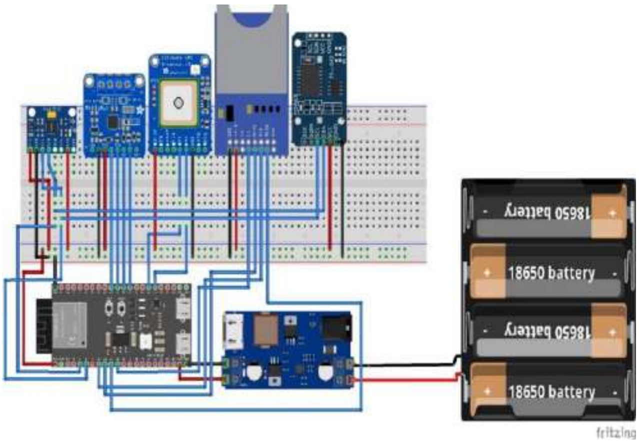

Fig. 3. Breadboard assembly of the complete monitoring circuit.

The PCB traces were then designed using KiCad, as shown in Fig. 4, before the final prototype was implemented inside an enclosure box.

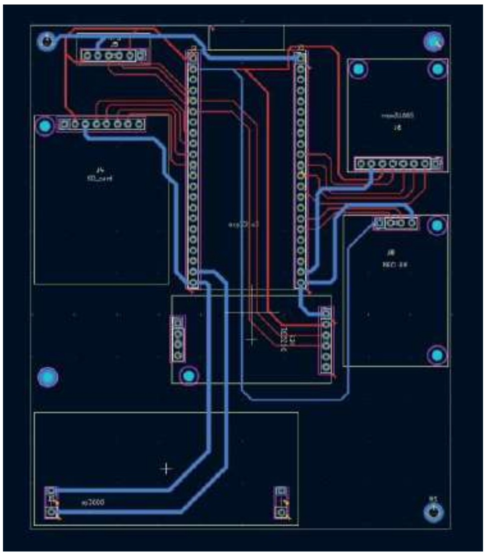

Fig. 4. PCB trace layout of the monitoring circuit, designed in KiCad.

4.2. Device testing

Testing was carried out to determine system performance from both the hardware and software sides, for each functional block of the system, covering the MPU6050, PT100, MAX31865, and NEO-8M GPS sensors that serve as inputs to the ESP32-S3 microcontroller, as well as the SD card module, the XY3606 step-down module, and the 18650 lithium battery. The PT100 sensor is used to monitor temperature within the refrigeration system, while the GPS module is used to obtain vehicle-location information directly. All processed data are transmitted to the server via the MQTT protocol; when an internet connection is not available, data are temporarily stored on the SD card as a buffer and re-sent once the connection is restored. The system is also supported by time synchronization using the GPS and RTC modules, and it is equipped with a monitoring and recovery mechanism to keep performance optimal.

4.3. Test results.

Sensor and module testing was carried out by comparing the data obtained against reference values from conventional measuring instruments, in order to determine the accuracy level of the sensors and modules used in this system. The results are shown in Table I.

TABLE I. Sensor Test Results

Parameter	Measured	Reference	Difference
PT100 (°C)	−15.5	−15.8	0.2
GPS (coord.)	−6.904921; 109.144543	Google Maps	± few m
RTC (time)	09.00	Digital clock	± 1 s

In addition to the results in Table I, testing of the MPU6050 sensor showed that it was able to detect vibration and acceleration changes on the X, Y, and Z axes directly through the ESP32-S3 microcontroller, with stable readings consistent with the actual vibration conditions during testing.

4.4. Discussions

Compared with earlier ESP32-based temperature and humidity monitoring systems that reported response times of around 1.9 seconds using a Firebase and Kodular stack [10], the prototype developed in this study extends single-parameter monitoring by fusing temperature, vibration, and location data within one pipeline, which is closer to the multi-sensor direction advocated in value-centric IoT food-supply-chain design [9] and in sensor-network-based perishable-supply-chain research [17] than to single-sensor temperature loggers. Where the ESP32-versus-Raspberry-Pi-Pico-W comparison found the ESP32 advantageous for real-time latency at the cost of higher power draw relative to the Pico W [11], the present system accepts that trade-off deliberately, since continuous MQTT transmission and SD-card buffering both benefit from the ESP32-S3's real-time responsiveness more than they would from the Pico W's lower power consumption. The 0.2°C deviation achieved by the PT100/MAX31865 pairing in this study is consistent with the high measurement accuracy reported for ANN-assisted cold-storage monitoring systems, which achieved error rates below 1% [12], suggesting that a well-calibrated RTD sensor can approach ANN-corrected accuracy without requiring an on-device learning model. The GPS positioning accuracy of a few meters obtained here also aligns with the reliability expected of GNSS-based vehicle tracking in comparable IoT logistics work [8]. Where computational and empirical studies of refrigerated truck bodies show that airflow pattern and box-loading configuration can create

Vol. 1 No. 5 July 2026
E-ISSN: 3132-5115
DOI: 10.65780/bima.v1i5.32

significant internal temperature non-uniformity [13], [14], the vibration data captured by the MPU6050 in this study provides a complementary, empirically grounded signal for cargo-handling events that a temperature sensor alone cannot reveal, supporting the broader argument that supply-chain visibility in fishery logistics benefits from multiple, jointly interpreted technologies rather than temperature monitoring in isolation [15], [18], [19]. Taken together, these comparisons indicate that the principal contribution of this research relative to prior single-purpose monitoring systems is not any single sensor's accuracy, but the integration of three previously separate monitoring functions — temperature, vibration, and location — into a single, MQTT-connected, offline-tolerant prototype purpose-built for the refrigerated-truck use case rather than for static cold storage.

5. CONCLUSION

Based on the research conducted, a prototype Internet of Things (IoT)-based intelligent cold chain control system using an ESP32-S3 microcontroller was successfully designed and implemented to monitor the distribution of marine products on refrigerated truck fleets in real time. The PT100 sensor paired with the MAX31865 module was able to perform stable and accurate temperature measurements down to −15°C in accordance with the temperature standard set by the company. The NEO-8M GPS module successfully provided accurate real-time vehicle-position information, although performance was not yet optimal inside multi-story buildings. The monitoring system developed is able to transmit sensor data via the MQTT protocol to a server or cloud platform, and to temporarily store data on an SD card as a buffer when the internet connection is disrupted. All hardware used — the ESP32-S3, PT100, MAX31865, MPU6050, NEO-8M GPS, SD card module, XY3606 step-down module, and 18650 lithium battery — functioned properly, so that the application of this data fusion-based monitoring system is able to improve the effectiveness of temperature, vibration, and location monitoring in order to maintain the quality of marine products throughout the cold chain.

SUGGESTIONS

The device that has been designed functions well, but it still has limitations that need to be evaluated under real-world usage conditions. A more stable internet network is needed for more reliable data transmission, and further testing at a larger fleet scale is required to determine the overall reliability of the system.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Very Kurniawan Bakti, M.Kom., as First Supervisor, and Mr. Abdul Basit, S.Kom., M.Tr.T., as Second Supervisor, for their guidance and direction throughout the preparation of this research, as well as CV. Mutiara Samudera Indonesia for granting permission and assistance during the observation and data-collection process.

REFERENCES

[1] H. Prasutiyon, Sutrisno, and R. Tambun, ‘The Contribution of the Maritime Sector to Economic Growth and Sustainable Welfare in Developing Countries’, Int. J. Integr. Sci., vol. 4, no. 5, pp. 833–842, 2025, doi: 10.55927/ijis.v4i5.227.

[2] B. Suseto, Z. Othman, and F. Bin Mohd Razalli, ‘An Overview of Indonesia’s Maritime Strategy’, Indones. J. Geogr., vol. 50, no. 2, p. 145, 2018, doi: 10.22146/ijg.27954.

[3] C. Amin, H. Mulyati, E. Anggraini, and T. Kusumastanto, ‘Impact of maritime logistics on archipelagic economic development in eastern Indonesia’, Asian J. Shipp. Logist., vol. 37, no. 2, pp. 157–164, 2021, doi: 10.1016/j.ajsl.2021.01.004.

[4] R. Badia-Melis, U. Mc Carthy, L. Ruiz-Garcia, J. Garcia-Hierro, and J. I. Robla Villalba, ‘New trends in cold chain monitoring applications – A review’, Food Control, vol. 86, pp. 170–182, 2018, doi: 10.1016/j.foodcont.2017.11.022.

[5] X. Nie, R. Zhang, L. Cheng, W. Zhu, S. Li, and X. Chen, ‘Mechanisms underlying the deterioration of fish quality after harvest and methods of preservation’, Food Control, vol. 135, p. 108805, 2022, doi: 10.1016/j.foodcont.2021.108805.

[6] H. Zhou et al., ‘Gelatin–Tea Tree Essential Oil Coating Improves the Quality, Flavor, and Micromolecular Metabolites of Squid (Illex argentinus) Muscle During Cold Storage’, Foods, vol. 14, no. 7, pp. 1–20, 2025, doi: 10.3390/foods14071160.

[7] H. Purwanto, M. Hermawan, C. Nainggolan, and B. Wibowo, ‘Design of an Automatic Temperature Recorder for Fishery Vessels Using Internet of Things Technology’, J. Appl. Eng. Technol. Sci., vol. 5, no. 2, pp. 1020–1050, 2024, doi: 10.37385/jaets.v5i2.4887.

[8] A. A. Jimoh, S. Nafiu Abubakar, Q. O. Oladuntoye, and A. S. Mafe, ‘Development and Implementation of Internet of Things Based Vehicle Tracking System’, J. Eng. Res. Dev., vol. 9, no. 5, 2025, doi: 10.70382/bejerd.v9i5.013.

[9] Z. Pang, Q. Chen, W. Han, and L. Zheng, ‘Value-centric design of the internet-of-things solution for food supply chain: Value creation, sensor portfolio and information fusion’, Inf. Syst. Front., vol. 17, no. 2, pp. 289–319, 2015, doi: 10.1007/s10796-012-9374-9.

[10] O. Nugraha, A. R. Hakim, and A. Hanif, ‘IoT Based Temperature and Humidity Monitoring System for Black Soldier Fly (BSF) Biopond Using ESP32’, J. Artif. Intell. Eng. Appl., vol. 5, no. 3, pp. 4882–4886, 2026, doi: 10.59934/jaiea.v5i3.2558.

[11] S. Supriyanto and S. U. Anggono, ‘Comparative Analysis of Power Consumption and Real-Time Performance Between Esp32 and Raspberry Pi Pico W in Iot-Based Temperature Monitoring Systems’, J. Teknol. Inf. Dan Komun., vol. 16, no. 1, pp. 176–182, 2025, doi: 10.51903/jtikp.v16i1.1147.

[12] H. Afreen and I. S. Bajwa, ‘An IoT-Based Real-Time Intelligent Monitoring and Notification System of Cold Storage’, IEEE Access, vol. 9, pp. 38236–38253, 2021, doi: 10.1109/ACCESS.2021.3056672.

[13] S. Liu, Q. Deng, Y. Sun, and P. Ding, ‘Research on efficient numerical method of air flow and heat transfer in a refrigerated truck’, Case Stud. Therm. Eng., vol. 71, p. 106270, 2025, doi: 10.1016/j.csite.2025.106270.

[14] J. So, S. Joe, S. Hwang, S. Jun, and S. Lee, ‘Analysis of the temperature distribution in a refrigerated truck body depending on the box loading patterns’, Foods, vol. 10, no. 11, pp. 1–20, 2021, doi: 10.3390/foods10112560.

[15] M. Mirzaei, B. Dehe, K. Weerasinghe, and H. Srivastava, ‘Enhancing Supply Chain Visibility in the Fishing Industry: The Role of Emerging Technologies and Their Affordances’, Oper. Supply Chain Manag., vol. 18, no. 2, pp. 146–160, 2025, doi: 10.31387/oscm0610462.

[16] B. Ye, J. Chen, L. Fu, and Y. Wang, ‘Application of nondestructive evaluation (NDE) technologies throughout cold chain logistics of

BIMA
BULLETIN OF INTELLIGENT MACHINES AND ALGORITHMS
Vol. 1 No. 5 July 2026
E-ISSN: 3132-5115
DOI: 10.65780/bima.v1i5.32

seafood: Classification, innovations and research trends', LWT, vol. 158, p. 113127, 2022, doi: 10.1016/j.lwt.2022.113127.
[17] A. Pal and K. Kant, 'Smart sensing, communication, and control in perishable food supply chain', ACM Trans. Sen. Netw., vol. 16, no. 1, 2020, doi: 10.1145/3360726.
[18] N. Natraja, 'AI and IoT Synergy for Intelligent Cold Chain Logistics', Int. J. Sci. Res. Eng. Trends, vol. 11, no. 2, pp. 2272–2276, 2025, doi: 10.61137/ijsret.vol.11.issue2.422.
[19] A. H. M. C. da Silva, M. K. da Silva, A. Santos, and L. A. Gómez-Malagón, 'A Systematic Review for Ammonia Monitoring Systems Based on the Internet of Things', IoT, vol. 6, no. 4, p. 66, 2025, doi: 10.3390/iot6040066.