From net to plate

transforming the seafood sector through the internet of things

Pandey, Vineet; Gupta, Sumit; Joshi, Deepika; Jagtap, Sandeep

Published in:
Seafood 4.0

DOI:
10.1016/B978-0-443-33750-5.00012-3

2025

Document Version:
Publisher's PDF, also known as Version of record

CHAPTER EIGHT

From net to plate: Transforming the seafood sector through the internet of things

Vineet Pandey[a], Sumit Gupta[b], Deepika Joshi[c] and Sandeep Jagtap[d,e]
[a]Department of Automation, Banasthali Vidyapith, Jaipur, India
[b]Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Noida, Uttar Pradesh, India
[c]St. Joseph's Institute of Management, Operations and Business Analytics, Bangalore, India
[d]Division of Engineering Logistics, Faculty of Engineering, Lund University, Lund, Sweden
[e]Sustainable Manufacturing Systems Centre, Cranfield University, Cranfield, United Kingdom

8.1 Introduction

The fourth industrial revolution, often referred to as "Industry 4.0," brings together digital, physical, and biological technologies to form smarter, interconnected systems. Various industries are undergoing significant technological advancements, and the seafood sector, known for its reliance on labor and resources, is no different. A new era of innovation, termed Seafood 4.0, is emerging, where the principles of Industry 4.0 are being applied to the production, processing, and distribution of seafood, transforming it from end to end (Hassoun et al., 2023). By incorporating advancements into every stage of the seafood value chain, Seafood 4.0 represents a shift from catch to consumer (Bastug, Arabelen, Vural, & Ali Deveci, 2020; García-Poza et al., 2020). This transformation, enabled by advanced technologies such as robotics, artificial intelligence, big data analytics, and particularly the IoT, aims to increase **the's** efficiency, sustainability, and transparency. It seeks to meet the growing demand for seafood while minimizing environmental impact and ensuring the health and safety of aquatic ecosystems (Misra et al., 2022; Subash et al., 2024). In today's world, where seafood consumption continues to grow and resources become scarcer, the application of technology to seafood production is essential. With rising global populations and the challenges posed by climate change, which make traditional fishing and aquaculture increasingly difficult, the seafood industry must adopt innovative approaches. Seafood 4.0 offers a strategic solution to these challenges, paving

Seafood 4.0: Digital, Physical, and Biological Realms from Sea to Table
DOI: https://doi.org/10.1016/B978-0-443-33750-5.00012-3

the way for more sustainable and resilient systems of seafood production. This chapter will delve into the impact of IoT technologies and their components on various aspects of seafood.

8.2 Importance of IoT in the seafood

Seafood 4.0 is fundamentally driven by IoT, a network of connected devices that collect, exchange, and analyze data in real time. By utilizing IoT, physical assets such as machinery, sensors, and processing equipment can communicate both with centralized systems and with each other, creating a responsive and adaptive ecosystem (Hassoun et al., 2022). This technology is revolutionizing every stage of the supply chain, from aquaculture and capture fisheries to processing, distribution, and retail (Grecuccio et al., 2020). Within the seafood sector, IoT serves a wide range of functions. In aquaculture, IoT devices are capable of monitoring water quality, feed levels, and the health of fish in real-time, ensuring optimal conditions for growth while reducing the risk of disease outbreaks (Ubina & Cheng, 2022). At processing facilities, IoT sensors track key metrics like temperature and humidity, which help to maintain the freshness and quality of seafood products (Hasnan & Yusoff, 2018; Hassoun et al., 2022). Furthermore, IoT-enabled tracking systems throughout the distribution process ensure that seafood is transported in conditions that preserve its freshness, significantly reducing waste. In the retail environment, IoT provides transparency to consumers by offering information on the origin, handling, and sustainability of seafood, thereby fostering greater trust. The integration of IoT within the seafood industry brings both economic and environmental advantages. It enhances operational efficiency and profitability by optimizing resource usage, minimizing waste, and improving traceability (Ojo et al., 2018; Rowan, 2023). Moreover, IoT contributes to sustainability by enabling more effective management of fish stocks and curbing overfishing, which helps to reduce the environmental impact of seafood production (Senturk et al., 2023; Subash et al., 2024). This chapter explores how IoT is shaping the future of Seafood 4.0, detailing its transformative role within the sector. It examines the wide range of IoT applications across the seafood value chain, presents real-life examples and case studies, and analyzes the benefits and challenges associated with adopting IoT. Additionally, it provides insights into how industry stakeholders can effectively navigate this technological shift.

8.3 Concept and fundamentals of IoT

IoT represents a transformative technology that has fundamentally changed the way we perceive and engage with the world. By connecting physical objects to their digital counterparts, IoT enables the integration of sensors, software, and other technologies into everyday items. These devices are able to share data over the internet, fostering a networked environment where they can communicate with one another autonomously. This interconnectedness generates real-time insights, promoting efficiency, convenience, and informed decision-making across a range of sectors.

8.3.1 Historical development and evolution

The evolution of IoT has spanned several decades, drastically changing how devices establish connections, as shown in Table 8.1. In the 1960s, the foundation for this technology was laid with the development of the Advanced Research Projects Agency Network (ARPANET), which laid the foundation of modern internet and industrial remote telemetry systems. Early applications focused on machine-to-machine (M2M) communication, setting the stage for further advancements. In 1990, a humble toaster became one of the first objects controlled online, showcasing the emerging possibilities of linking everyday items to the internet.

During the 1990s, the convergence of radio-frequency identification (RFID) technology and mobile GPRS helped bridge the gap between the physical and digital worlds. In 1999, Kevin Ashton formally coined the term "Internet of Things," applying RFID tags to supply chain management, further expanding the concept.

The 2000s saw the introduction of industrial IoT into consumer markets, bolstered by the advent of Internet Protocol version 6 (IPv6). Supplying IP addresses and additional security to the system allowed it to connect billions of devices. The mid-2010s marked a pivotal moment for IoT, as smart cities and Industry 4.0 capitalized on the potential of IoT through the utilization of cloud computing and big data analytics (Stojanovic & Chaudhary, 2023). These developments enabled the efficient capture, storage, and processing of enormous volumes of data generated by IoT devices.

In recent years, IoT has continued to evolve rapidly, driven by technological advancements. The introduction of 5G has notably reduced latency by shortening the distance data needs to travel, resulting in faster and more reliable communication. This has paved the way for real-time applications such as autonomous vehicles and remote healthcare. Furthermore, the

Table 8.1 Historical development of IoT (Halias, 2021).

Period	Key events/ technologies	Significance
1960s–1980s	ARPANET (1969)	Early development of networking and machine-to-machine (M2M) communication, the foundation for IoT concepts.
	Remote telemetry in industrial settings	Enabled monitoring and control of machines from a distance.
1990s	First internet-connected device (1990)	John Romkey's toaster marked the beginning of everyday objects connected to the internet.
	Kevin Ashton coined "Internet of Things" (1999)	The term IoT was introduced, focusing on using RFID to track products in supply chains.
	Rise of RFID and GPRS	Enabled object tracking and M2M communication via mobile networks, enhancing logistics and asset management.
2000s	MIT's Auto-ID Labs (2003–2004)	Early research on large-scale interconnected objects.
	Introduction of IPv6	Essential for expanding the number of devices connected to the internet with an almost limitless number of IP addresses.
	Smart homes, wearables	Consumer IoT applications like connected thermostats and fitness trackers emerged.
2010s	Cloud computing & considerable data convergence	Enabled mass data collection, storage, and analysis from IoT devices, driving intelligent applications.
	Smart cities & Industry 4.0	IoT expanded to urban infrastructure and manufacturing, leading to smarter cities and automated industrial systems.
	IoT standards & protocols	Efforts to create interoperability between IoT devices through standardization (IETF, IEEE).
Late 2010s–Present	Edge computing	Addressed bandwidth and latency challenges by processing data closer to the devices, crucial for real-time applications like autonomous vehicles.
	5G networks	High-speed, low-latency communication enabled broader IoT applications.
Future	AI, ML, and quantum computing integration	IoT becomes more autonomous and intelligent, playing central roles in smart infrastructure, personalized healthcare, and sustainability initiatives.

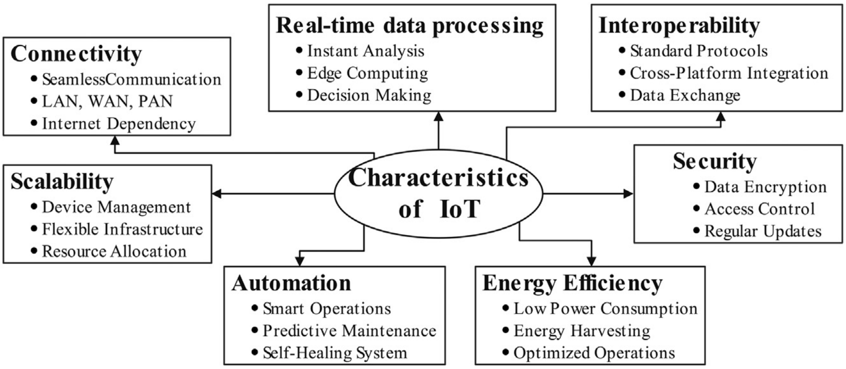

Figure 8.1 Characteristics of IoT (Author contribution).

integration of AI, machine learning, and quantum computing into IoT systems is set to propel the field even further (Islam et al., 2024). These technologies are driving advancements in smart infrastructure, precision medicine, and efforts toward environmental sustainability. IoT's ongoing development holds the potential to revolutionize a wide range of industries, transform urban landscapes, and leave a lasting impact on our daily lives.

8.3.2 Key characteristics of IoT

IoT possesses several distinctive features that set it apart from traditional internet-based systems. These key characteristics—connectivity, scalability, interoperability, and real-time data processing—are fundamental to its functionality and provide substantial value across a wide range of applications. Fig. 8.1 illustrates the primary attributes of the IoT.

- **Connectivity:** Central to IoT is its ability to establish connections between devices. Connectivity refers to the capability of devices to link to the internet and communicate with one another, facilitating the seamless exchange of data between systems, devices, and users (Atzori et al., 2010; Bassi et al., 2013). This coordination is achieved through various wireless communication protocols such as Wi-Fi, Bluetooth, Zigbee, and cellular networks, although wired connections can also be used. The main benefit of this connectivity is the ability to monitor and control devices remotely, a feature that enhances applications like smart homes, industrial automation, and healthcare (Alaa et al., 2017).
- **Scalability:** Another key aspect of IoT is its scalability, which allows systems to accommodate an ever-growing number of connected devices without compromising performance. As IoT networks expand, they must

be capable of managing increased data traffic and continuing to operate efficiently. Scalability is especially vital in large-scale deployments such as smart cities or agricultural monitoring systems (Ayaz et al., 2019; Verdouw et al., 2016), where the network may need to expand to include additional sensors, devices, and areas (Xu et al., 2014). This ability to scale ensures that systems can grow with minimal alterations to the existing infrastructure.

- **Interoperability:** A crucial feature of IoT is interoperability, which enables different devices and systems to work together, regardless of the manufacturer or technology involved (Al-Fuqaha et al., 2015). In any IoT ecosystem, this is essential, as multiple devices from various vendors must communicate and share data effectively. Standard communication protocols and interfaces ensure that devices can interpret the data and commands from one another, which is particularly important in environments like smart homes and industrial IoT systems, where numerous devices must interact to deliver desired outcomes.
- **Real-Time Data Processing:** IoT devices continuously gather data from their surroundings and transmit it to other devices or centralized systems in real time. The ability to process this data instantly is critical for applications that require immediate responses, such as autonomous vehicles, where split-second decisions can be the difference between safety and catastrophe (Riggins & Wamba, 2015). Real-time data processing also allows businesses to streamline their operations, reduce downtime, and enhance customer experiences by responding to events as they occur.

8.3.3 Advantages of IoT characteristics in different applications

The characteristics of IoT, such as connectivity, scalability, interoperability, and real-time processing, offer numerous advantages across various applications. In the context of smart homes, connectivity enables homeowners to control appliances, lighting, and security systems remotely via digital platforms, significantly enhancing convenience and safety. As smart homes evolve, the scalability of IoT allows for the seamless integration of new devices over time, while interoperability ensures that products from different manufacturers function harmoniously within a single system. Real-time data processing further enhances this, as the system can automatically adjust to user behavior or environmental changes, such as lowering the heating when the house is unoccupied (Balaji et al., 2019).

In industrial automation, IoT connectivity links machines, sensors, and central control systems, resulting in improved efficiency and coordination. A factory's IoT network can be easily expanded with the addition of new equipment or production lines, without disrupting operations, thanks to its scalability (Serpanos & Wolf, 2017). Interoperability allows machinery from different manufacturers to work together in an integrated manner, while real-time data processing enables predictive maintenance, which reduces downtime and boosts overall productivity.

In healthcare, IoT devices, such as wearable sensors, track patients' vital signs in real time and send the data directly to healthcare providers for immediate analysis. This connectivity allows for timely interventions, potentially improving patient outcomes. The scalability of IoT systems enables healthcare providers to accommodate more patients as needed, while interoperability ensures that devices from various suppliers work together to provide a comprehensive view of a patient's health. Real-time data processing allows health professionals to detect issues before they escalate to critical levels, enhancing the quality of care.

8.3.4 Components of IoT ecosystems

The IoT ecosystem consists of several essential components that work together to collect, transmit, process, and act on data. These include sensors, actuators, communication networks, and data processing units, all of which are crucial to the functioning of an IoT system.

- **Sensors** are at the forefront of any IoT system, tasked with gathering data from the physical environment. They can measure a range of factors such as temperature, humidity, motion, light, or sound. The primary function of a sensor is to convert physical occurrences into electrical signals, which can then be transmitted to other parts of the system for further analysis. Various types of sensors are utilized in IoT applications, including environmental, biometric, motion, and chemical detectors, depending on the system's requirements (Kumar & Mallick, 2018).
- **Actuators**, on the other hand, perform actions based on the information received from sensors or processing units. While sensors are responsible for collecting data, actuators are the components that interact with the physical world, executing tasks like opening a valve, turning on lights, or starting a motor (Kamarudin et al., 2020). In an IoT system, actuators receive commands from a central processing unit and act accordingly to achieve the desired result. For instance, in a smart irrigation system,

sensors might monitor soil moisture, and when the soil becomes dry, actuators activate sprinklers.

- **Communication networks** form the pathways through which data travels within an IoT system, whether via wired or wireless means. Wireless technologies, such as Wi-Fi, Bluetooth, Zigbee, and cellular networks, are often favored due to their flexibility and ease of deployment (Sikimic et al., 2020). The choice of communication network depends on factors such as range, data rate, power consumption, and the specific operating environment of the IoT system.
- **Data processing units** serve as the brain of an IoT system. They collect the data transmitted by sensors, process it, and make decisions based on predefined algorithms or machine learning models. Data processing can either be done locally, at the source of the data (known as edge computing), or remotely in the cloud. Edge computing minimizes latency and bandwidth by processing data closer to its origin, while cloud computing handles more complex tasks and stores large amounts of data for extended periods.

The broader IoT ecosystem is a network of interconnected devices, platforms, services, and stakeholders that collaborate to deliver IoT solutions. This ecosystem includes a range of participants, such as device manufacturers, software developers, network providers, cloud service providers, and end-users. Each of these players contributes to the overall efficiency and functionality of IoT systems.

- **Original Equipment Manufacturers (OEMs)** create the sensors, actuators, and communication hardware that form the physical backbone of the IoT ecosystem.
- **Software developers** build the applications and platforms that allow IoT devices to operate, process incoming data, and offer user-friendly interfaces.
- **Network providers** supply the infrastructure that enables devices to communicate with each other and with the internet.
- **Cloud service providers** facilitate data storage and complex processing, which is particularly important for systems requiring extensive data analysis and machine learning capabilities.

End-users, whether individuals or businesses, interact with these systems to accomplish tasks efficiently, safely, and with greater insight. The IoT ecosystem continues to evolve, shaped by technological progress and growing demand for connected solutions (Tyagi & Kumar, 2020). As the IoT landscape expands, the collaboration between various stakeholders in

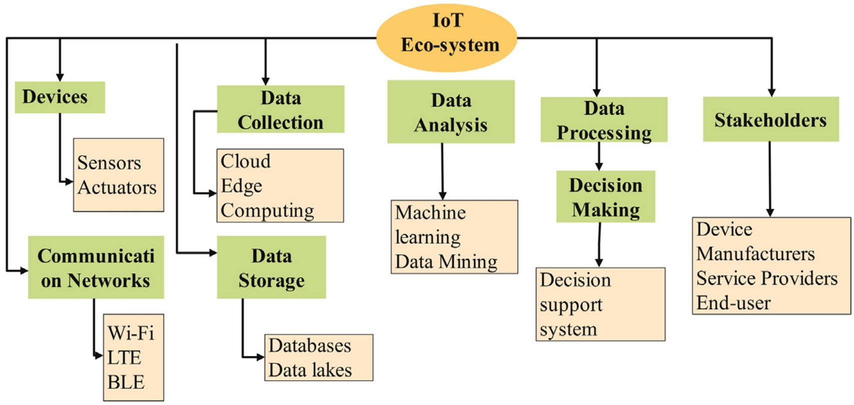

Figure 8.2 IoT ecosystem (Author contribution).

developing new applications and tackling emerging challenges becomes increasingly significant.

IoT is undoubtedly one of the most transformative technological advancements of the modern era, designed to create a more connected and intelligent world. With its potential to revolutionize industries and improve daily life, understanding the components and ecosystem of IoT is essential for driving innovation and harnessing its full capabilities. As IoT technology rapidly advances, it plays an ever more critical role in shaping the future of both technology and society. The IoT ecosystem is represented in Fig. 8.2.

8.4 Technical aspects of IoT implementation

Addressing the technical aspects of IoT implementation is multifaceted, requiring expertise across several disciplines, such as hardware, software, communication protocols, cloud computing, and cybersecurity. A successful IoT deployment necessitates robust infrastructure, seamless interaction between physical devices and digital platforms, and reliable methods for data collection, transmission, and analysis. Fig. 8.3 shows the IoT architecture with its components.

The following sections delve into the core components involved in IoT implementation in the seafood industry:

8.4.1 The role of IoT in enhancing efficiency and sustainability in the seafood industry

The seafood industry succeeded in transformation by incorporating the IoT, which brings efficiency along with sustainability improvements and provides

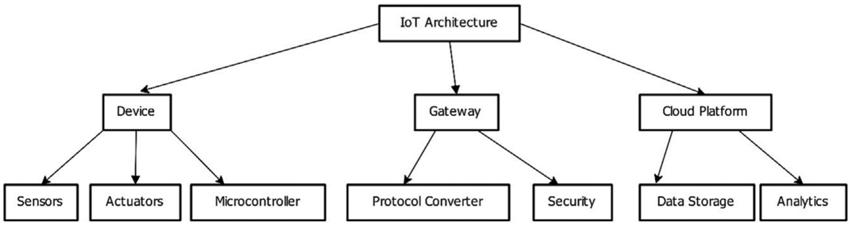

Figure 8.3 IoT architecture and components (Author contribution).

enhanced transparency. The operation of IoT systems depends on edge devices (Datta & Bonnet, 2017), gateways, cloud services (Qiu et al., 2020), and communication networks that work together for seafood production optimization, as well as storage activities and distribution protocols. Electronic devices used in storage facilities, along with aquaculture tanks and fishing vessels, employ real-time data collection through local processing systems to enable quick environmental response. Gateways function as processors alongside other responsibilities to combine data from various sources and then transmit the processed information to cloud platforms. Cloud services bring the needed infrastructure through storage facilities and processing potential to analyze large-scale data so businesses can conduct analytics and leverage machine learning to detect equipment breakdowns or environmental changes. Wi-Fi and Zigbee, together with LoRaWAN and NB-IoT, provide secure network connection paths that enable continuous data transmission between seafood operational elements and end-user interfaces.

The IoT enables seafood operations through devices that track temperature alongside pH levels and salinity measurements and GPS settings to achieve suitable manufacturing and distribution conditions. Temperature sensors preserve proper storage procedures alongside food regulations by monitoring conditions that stop deterioration from occurring. Simultaneously, pH and salinity sensors (Sehrawat & Gill, 2019) assess water quality in aquaculture tanks to nurture aquatic species' health. The tracking of fishing vessels through GPS sensors enables monitoring of sustainable seafood practices as well as end-to-end product trackability from fishing boats to commercial markets. Sensor data triggers machine-based automation (Mustapha et al., 2021), which activates cooling systems and regulates water flow controllers. The efficient management of generated data stands as a mandatory prerequisite for properly operating IoT systems. The edge processing system performs instant data filtering combined with real-time aggregation functions, and cloud storage handles scalability needs and ensures security for data. The integration of advanced analytics through machine learning improves decision-making that enables better operational efficiency (Babun et al., 2021) and sustainability through their ability to forecast challenges and track trends. The seafood industry will transform into a more efficient, transparent sustainable system through ongoing developments in IoT technology, which will advance the global food production methods.

8.4.2 IoT platforms and solutions for the seafood industry

The IoT revolutionized the seafood industry through its data collection software and analysis automation, which provide users with real-time information platforms. Such platforms play a fundamental role in quality seafood product assessment and sustainability improvement, and operational efficiency advancement. The seafood industry adopts three major IoT platforms, which are AWS IoT, Microsoft Azure IoT, and Google Cloud IoT. The platforms specialize their features to match the specific requirements of seafood business operations. AWS IoT enables safe and expandable connectivity and data processing through AWS Lambda and AWS Kinesis to execute real-time analysis and machine learning for forecasting maintenance requirements, along with quality control needs. The features of Azure IoT comprise device management and real-time data processing through Azure Stream Analytics along with predictive analytics via Azure Machine Learning, which make the platform suitable for seafood traceability and environmental monitoring (Popovic et al., 2024). The data-driven analytics capabilities of Google Cloud IoT are strengthened by Google Cloud AI, together with Google BigQuery and dataflow systems, which provide seafood operators with an optimal solution for making data-informed operational choices.

Selection among these platforms requires evaluation based on scalability, performance, and management of devices and data analytical features. Specifications of AWS and Azure, as well as their extensive scalability, match their strong integrations, while Google Cloud leads with data analytics functions that emphasize machine learning capability. Azure IoT provides exceptional advantages for remote edge computing operations, including fishing vessels and aquaculture farms that need real-time processing capabilities (Domínguez-May et al., 2024). When choosing a platform, businesses need to analyze how well it matches their requirements for integration, together with its scalability, its edge computing ability, and its operational cost. Several studies in the seafood industry demonstrate how IoT creates fundamental changes in operations. AWS IoT enabled a major seafood company to track products across its supply chain better, which resulted in improved sustainability and transparency. The aquaculture farm put Azure IoT technology to use for monitoring and predictive analytics to achieve optimal water quality management and feeding operation performance. The seafood company utilized Google Cloud IoT to predict fish movements through machine learning algorithms for optimizing their fishing route efficiency. The examined use cases show how IoT technology can drive seafood industry improvements across operational excellence and environmental sustainability, along with product tracking abilities.

8.5 IoT applications in the seafood

The integration of IoT is becoming pivotal to creating a sustainable, transparent, and more efficient seafood industry. IoT technology allows seamless data collection, transmission, and analysis at each stage of the seafood supply chain, from harvesting and processing through to distribution and consumption. This technology is set to transform the seafood industry by offering real-time monitoring, autonomous decision-making, and enhanced traceability, ensuring high-quality products while meeting the growing demand for sustainability and transparency. Key applications of IoT in the seafood industry include traceability, aquaculture management, fishing operations, and supply chain optimization.

8.5.1 Traceability and transparency

Traceability and transparency are two of the most pressing challenges facing the seafood industry. IoT improves traceability significantly by providing a continuous stream of data that tracks seafood throughout its journey along the supply chain. With the help of sensors and other IoT devices, companies can monitor and control critical factors such as temperature, location, and handling conditions at every point in the logistics process, ensuring that the catch remains fresh (Mehannaoui et al., 2023).

For instance, the Norwegian firm Mowi implemented an IoT-based traceability system through marine harvest. Using RFID tags, sensors, and cloud platforms, Mowi tracks each product from the moment of catch to its final consumption. Data is updated in real-time to guarantee product quality, enhancing both operational efficiency and consumer trust by providing detailed information about the seafood's origin and sustainability practices (Mostaccio et al., 2023).

Similarly, Thai Union Group, one of the largest seafood companies globally, uses IoT to manage its cold chain systems. IoT sensors continuously monitor the temperature and humidity of seafood products during transportation and storage, alerting operators if conditions deviate from the ideal (Popa et al., 2019). This not only reduces spoilage and waste (Jagtap et al., 2019) but also provides consumers with greater confidence in the quality and safety of the seafood they purchase.

8.5.2 Monitoring and management

Aquaculture, the farming of aquatic organisms such as fish and shellfish, has become a critical part of the seafood industry. The success of aquaculture, however, hinges on maintaining optimal conditions for the species being farmed (Pal & Kant, 2018). IoT has brought about a new level of precision in aquaculture by allowing real-time monitoring and management of the environment. IoT systems typically include sensors that measure key water quality parameters such as temperature, pH, dissolved oxygen, and salinity, all of which are crucial for maintaining the health and growth of the farmed species (Stentiford et al., 2012).

In Vietnam, an IoT-based system has been implemented to monitor shrimp farms, continuously tracking water quality and feeding patterns. This system has enabled farmers to optimize feeding schedules and improve water conditions, leading to higher yields, reduced costs, and lower mortality rates among shrimp populations (Dar et al., 2020; Rosaline & Sathyalakshimi, 2019). In Norway, salmon farms have adopted integrated IoT systems to monitor fish behavior, water quality, and feeding habits. Underwater cameras and sensors track fish activity, allowing farmers to make real-time adjustments to feeding rates and detect early signs of disease. This proactive approach has resulted in improved fish health, increased production, and more sustainable aquaculture practices.

8.5.3 Enhancing fishing operations

The fishing industry faces numerous challenges, including overfishing, bycatch, and the degradation of marine ecosystems. IoT offers a range of solutions to optimize fishing routes, monitor catches, and ensure compliance with regulations, making fishing practices more sustainable (Rowan, 2023).

IoT technology can be installed on fishing vessels to gather real-time data on ocean conditions, fish stocks, and vessel performance. This data is essential for optimizing fishing routes, reducing fuel consumption, and increasing efficiency. For example, IoT-enabled GPS and sonar systems can help fishers locate abundant fish stocks more accurately, reducing the time spent at sea and minimizing environmental impact.

A notable example is the "eCatch" platform, developed in collaboration with fishers on the U.S. West Coast. This IoT-based system allows fishers to record their catches via a mobile app, sharing the data with other fishers and regulatory bodies to improve fish stock management and ensure compliance with quotas. The system has played a key role in reducing overfishing and promoting sustainable fisheries (Merrifield et al., 2019).

IoT also helps monitor fishing activities to ensure vessels operate within legal boundaries and adhere to sustainable practices. This level of monitoring helps prevent illegal, unreported, and unregulated fishing, which poses a significant threat to marine biodiversity and the long-term viability of fish stocks (Little et al., 2015).

8.5.4 Case studies in seafood supply chain

The seafood supply chain involves multiple stages, from harvesting and processing to distribution and retail. IoT is revolutionizing this supply chain by enabling real-time visibility, improving product quality, and ensuring that seafood products remain intact throughout their journey.

A compelling case is Provenance, a technology company focused on supply chain transparency, which collaborated with the World Wide Fund for Nature (WWF) and Southeast Asian fisheries to integrate IoT and blockchain into the tracking of tuna (Provenance, 2016). Sensors attached to the tuna provided real-time data on location, temperature, and handling conditions, with all information securely stored on a blockchain ledger. This system ensured that the tuna was sourced sustainably and legally, combating illegal fishing and giving consumers verified information about the seafood they were purchasing (Tolentino-Zondervan et al., 2023).

In Iceland, Trackwell, a fleet management platform provider, uses IoT to monitor fishing vessels' position, fuel consumption, and catch. This system has enabled Icelandic fishing fleets to optimize their activities, reduce fuel use, and improve efficiency, significantly enhancing both productivity and profitability (Vollen & Haddara, 2019).

IoT is also making an impact on cold chain management within the seafood supply chain. Thai Union Group, for instance, has implemented an IoT-based system to monitor temperature and humidity levels during seafood storage and transport. This ensures the freshness and quality of seafood products while reducing spoilage, saving costs, and improving profitability.

The benefits of IoT in the seafood industry are far-reaching, offering enhanced product quality, greater traceability, and improved sustainability. IoT provides real-time data that drives better decision-making, making the seafood supply chain more efficient, transparent, and resilient (Merrifield et al., 2019). As IoT continues to be integrated into seafood production, distribution, and consumption, it will play a leading role in shaping a more sustainable and secure global food system.

8.6 Challenges and solutions in IoT adoption

Adopting IoT technology presents a variety of challenges across technical, regulatory, legal, economic, and social dimensions. Success in IoT deployment relies on a clear understanding of these challenges and the implementation of practical solutions (Rawajbeh et al., 2023). This section explores the difficulties associated with IoT adoption, potential strategies to overcome them, and the practical considerations for achieving successful IoT integration. These challenges are grouped into technological issues, regulatory and legal concerns, economic and social barriers, and strategies for overcoming them.

8.6.1 Technological issues

- **Scalability***:* As IoT systems expand, managing an increasing number of devices and the vast amount of data generated can strain infrastructure and performance. Ensuring that networks, storage, and processing systems can handle this growth without compromising efficiency is a critical challenge (Guo et al., 2018). Potential solutions are:
- **Cloud Computing:** Using platforms like AWS, Azure, or Google Cloud allows companies to scale resources up or down as needed, providing elastic computing, storage, and analytics capabilities.
- **Edge Computing:** Distributing processing closer to the data source reduces the burden on central systems, improving the real-time handling of data. By enabling local data processing, edge devices can alleviate bandwidth and processing constraints on central servers.
- **Interoperability:** Many IoT devices come from different manufacturers and may use varying communication protocols, leading to compatibility

issues. This lack of standardization can result in inefficient systems and integration problems (Noura et al., 2019). Possible solutions are:

- **Standardization:** Adopting common standards and protocols such as MQTT or CoAP can enhance device compatibility and promote seamless communication.
- **Middleware Solutions:** Intermediary platforms can act as bridges between incompatible systems, facilitating better integration and communication between different IoT devices.
- **Power Consumption:** Many IoT devices operate on batteries and must balance power consumption with functionality. Excessive power use leads to frequent battery replacements, increasing maintenance costs, and reducing operational efficiency. Possible solutions are:
- **Low-power Protocols:** Communication protocols like Zigbee or **Long Range Wide Area Network (**LoRaWAN), designed for low power consumption, can extend device battery life.
- **Energy Harvesting:** Technologies that harvest energy from solar or kinetic sources can be integrated into IoT devices, reducing the need for battery replacements and extending operational lifespans.

8.6.2 Regulatory and legal issues

- **Regulatory Considerations*:*** IoT systems must comply with a complex array of regulations relating to data protection, privacy, and cybersecurity (Jindal et al., 2018). Meeting requirements such as the General Data Protection Regulation (GDPR) in Europe or the California Consumer Privacy Act (CCPA) in the U.S. is crucial for legal compliance.
- **Strategies for Compliance:**
- **Data Encryption:** Implementing strong encryption protocols for data transmission and storage helps protect sensitive information and ensures compliance with data protection regulations (Eduardo, 2017).
- **Audits:** Regular security audits and risk assessments can ensure ongoing compliance with ever-evolving regulatory requirements.
- **Legal Considerations:** Legal challenges in IoT adoption may include issues surrounding data ownership, liability for data breaches, and intellectual property disputes (DeHondt, 2019).
- ***Strategies to Overcome Legal Difficulties:***
- **Legal Agreements*:*** Clear contracts outlining data ownership, liability, and compliance responsibilities can help mitigate legal risks.

- **Legal Counsel*:*** Engaging legal experts with a specialism in IoT and data privacy laws can provide guidance in navigating complex legal landscapes and ensuring compliance.

8.6.3 Economic and social barriers

- **Economic Considerations*:*** The cost of implementing IoT solutions can be prohibitive, particularly for smaller organizations. Expenses include device acquisition, network infrastructure, data storage, and analytics software (Mishra et al., 2022).
- ***Cost Considerations***
- **Cost-Benefit Analysis:** Conducting thorough cost-benefit analyses can help organizations assess the potential return on investment and justify the initial expense.
- **Funding and Incentives:** Seeking funding from government programs, grants, or industry associations can help offset the financial burden of IoT implementation.
- **Social Barriers:** Resistance to IoT adoption can stem from concerns over job displacement, privacy issues, and changes in workplace practices. Ensuring social acceptance is key to a successful rollout.
- ***Strategies to Overcome Social Barriers:***
- **Change Management:** Implementing change management strategies, including training and communication plans, can address concerns and help facilitate smoother adoption.
- **Stakeholder Engagement:** Involving stakeholders early in the process and addressing their concerns can foster support and acceptance of IoT technologies.

8.6.4 Strategies overcoming challenges

- **Pilot Programs:** Running pilot projects allows organizations to identify and address potential problems before full-scale deployment. Pilot programs provide valuable insights into the technology's performance and allow for improvements to be made.
- **Scalable Solutions:** Choosing scalable technologies that can grow with the business helps avoid bottlenecks and ensures long-term viability.
- **Interdisciplinary Approach**: Collaborating with technology providers, regulatory bodies, and industry experts can help organizations address the technical, legal, and operational challenges associated with IoT adoption (Martens et al., 2022).

8.6.5 Examples of IoT projects successfully applied

- **Smart Farming:** A major agricultural business used IoT solutions to monitor crop health and soil conditions in real time. By integrating sensors and data analytics, the company optimized irrigation schedules, reducing water consumption and improving crop yields. Scalable cloud services and stakeholder engagement were key to the project's success (Karunathilake et al., 2023).
- **Manufacturing Efficiency:** A manufacturing firm applied IoT for predictive maintenance, reducing downtime and maintenance costs. By deploying machine sensors and analyzing wear patterns, the company optimized its operations, with edge computing and machine learning playing pivotal roles (Kalla & Smith, 2024).

In adopting IoT technologies, various challenges exist, and it is yet up for discussion how successful the implementations of the solutions proposed are. Overall, technological advancement, regulatory compliance, economic planning, and societal acceptance, when approached correctly, allow businesses to conquer all challenges associated with IoT adoption and, therefore, its transformative potential. Organizational experiences that overcome such challenges are an excellent guide for others in sharing insights and best practices on implementing IoT in their processes.

8.7 Innovations in IoT for the seafood industry

The IoT landscape is continuously evolving, with emerging technologies set to shape the future of the seafood industry. Advances in connectivity, data analytics, and automation will drive more efficient, sustainable, and data-driven business practices.

8.7.1 Emerging IoT technologies

- **5G Technology:** The introduction of 5G networks promises ultra-fast data speeds, lower latency, and the ability to support a higher density of devices. For the seafood industry, 5G enables real-time monitoring and control of fishing vessels, aquaculture systems, and supply chains.
- **Edge Computing:** By processing data closer to its source, edge computing reduces latency and bandwidth requirements. This technology can be used in aquaculture to monitor water quality or onboard fishing vessels to process catch data, allowing for quicker decision-making and optimized operations.

- **AI Integration:** Integrating artificial intelligence with IoT systems allows for more sophisticated data analysis and automation. AI can predict equipment failures, optimize feed management in aquaculture, and streamline logistics by forecasting demand (Singh & Kaunert, 2024).

8.7.2 Advances in IoT devices and networks

- **Sensor Technology Innovations:** Advances in sensor technology are making IoT devices more accurate and affordable. Innovations include miniaturized sensors for environmental monitoring and biosensors for assessing fish health. These technologies allow for precise data collection in aquaculture and supply chain operations.
- **Communication Networks:** Low-power wide-area networks (LP-WAN), including protocols like LoRaWAN and NB-IoT, provide reliable connectivity for remote IoT systems. These networks are ideal for offshore fishing operations or isolated aquaculture farms, where continuous data transmission is critical.

In this regard, the efficiency and effectiveness of IoT systems in enhancing the capture and aquaculture seafood industry may be boosted by the combination of intelligent sensors and communication networks. Innovations at the level of sensor technologies reveal more accurate and real-time data. Enhanced communication networks ensure decent quality and reliable data transmission over long distances (Zhang et al., 2023). These enable improved decision-making, decreased operational costs, and increased productivity through timely interventions and resource usage optimization.

8.7.3 Possible consequences in the seafood industry

- **Long-Term Effects:** The long-term effects that IoT technology has on the seafood industry are profound. IoT allows better visibility and traceability along the seafood value chain from catch to consumer. Improved data capture and analyses translate into improved quality control, regulation compliance, and sustainable methods. For instance, real-time monitoring conditions in aquaculture can help avoid over-feeding and waste, while data-driven insights enable the establishment of fishing methods that are more efficient and environmentally friendly (Ismail et al., 2023).
- **Vision for Seafood 4.0:** Seafood 4.0 is a next-generation seafood industry revolution imposed by IoT and other advanced technologies. It is a completely integrated supply chain whereby data flows smoothly

in real-time between stakeholders, offering end-to-end traceability, automated decision-making, and predictive analytics. Innovative aquaculture systems, autonomous vessels for fishing, and enhanced analytics platforms—the key features of Seafood 4.0—can all come together to introduce more efficiency, transparency, and sustainability to this industry (Subash et al., 2024).

8.7.4 Innovations propelling seafood 4.0

IoT forms the core of Seafood 4.0, driving innovations that transform traditional practices into more intelligent and data-driven ones. The IoT systems allow for continuous environmental monitoring, automation in aquaculture systems, and tracking of seafood products in real-time through the supply chain. A technological premise for the broader goals of Seafood 4.0 includes sustainability, quality enhancement, and operational efficiency. IoT for the seafood industry is focused on several key areas:

- **Integration of IoT with Blockchain:** Integrating the strengths of IoT with blockchain technology is bound to improve seafood supply chain visibility and trace the origin and handling of any product in a tamper-proof way (Adhikari & Ramkumar, 2023).
- **Smart Aquaculture Systems Development:** Further development relating to sensors, AI, and automation creates an evolving sophistication capable of autonomous optimization of conditions in aquaculture, with finally reduced environmental impacts (Biazi & Marques, 2023).
- **Improved Analytics:** Improvement in analytics and machine learning allows better prediction and optimization, from market trends to better fish health management.

Concisely, the future of IoT as applied in the seafood industry is heralded by emerging technologies, including 5G, Edge, and AI, which seek to raise efficiency operations and advance toward Seafood 4.0. The improvement in sensor technology and communication networks would raise the precision and dependability of the IoT system. Long-term advantages range from increased sustainability to better traceability. By innovating and exploring new research directions, the seafood industry can leverage IoT to achieve more intelligent, efficient, and sustainable practices.

8.8 Conclusion

The integration of IoT into the seafood industry will result in a transformative shift, enhancing efficiency, productivity, and sustainability throughout the sector. By processing data in real time and providing seamless connectivity, IoT systems can optimize aquaculture, fisheries, and supply chains from primary production to end consumption. Emerging technologies, such as 5G, edge computing, and AI, will continue to shape the future of the seafood industry, driving it toward a more intelligent, sustainable, and transparent model. Embracing these innovations and addressing current challenges will allow the seafood industry to reap the long-term benefits of IoT, setting the stage for the realization of Seafood 4.0.

References

Adhikari, N., & Ramkumar, M. (2023). IoT and blockchain integration: Applications, opportunities, and challenges. *Network, 3*(1), 115–141. doi:10.3390/network3010006.

Alaa, M., Zaidan, A. A., Zaidan, B. B., Talal, M., & Kiah, M. L. M. (2017). A review of smart home applications based on internet of things. *Journal of Network and Computer Applications, 97*, 48–65. doi:10.1016/j.jnca.2017.08.017.

Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys and Tutorials, 17*(4), 2347–2376. doi:10.1109/COMST.2015.2444095.

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer Networks, 54*(15), 2787–2805. doi:10.1016/j.comnet.2010.05.010.

Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., & Aggoune, E.-H. M. (2019). Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk. *IEEE Access, 7*, 129551–129583. doi:10.1109/ACCESS.2019.2932609.

Babun, L., Denney, K., Celik, Z. B., McDaniel, P., & Uluagac, A. S. (2021). A survey on IoT platforms: Communication, security, and privacy perspectives. *Computer Networks, 192*. doi:10.1016/j.comnet.2021.108040.

Balaji, N. , K., & Santhakumar, R. (2019). IoT technology, applications and pplications and challenges: A contemporary survey. *Wireless Personal Communications, 108*(1), 363–388. doi:10.1007/s11277-019-06407-w.

Bassi, A., Bauer, M., Fiedler, M., Kramp, T., Van Kranenburg, R., Lange, S., & Meissner, S. (2013). Enabling Things to Talk: Designing IoT Solutions with TheIoT Architectural Reference Model (p. 379). Springer Nature. doi:10.1007/978-3-642-40403-0.

Bastug, S., Arabelen, G., Vural, C. A., & Ali Deveci, D. (2020). A value chain analysis of a seaport from the perspective of Industry 4.0. *International Journal of Shipping and Transport Logistics, 12*(4), 367–397. doi:10.1504/IJSTL.2020.108405.

Biazi, V., & Marques, C. (2023). Industry 4.0-based smart systems in aquaculture: A comprehensive review. *Aquacultural Engineering, 103*. doi:10.1016/j.aquaeng.2023.102360.

Datta, S. K., & Bonnet, C. (2017). An edge computing architecture integrating virtual IoT devices. In *2017 IEEE 6th global conference on consumer electronics, GCCE 2017* (pp. 1–3). doi:10.1109/GCCE.2017.8229253.

Da Xu, L., He, W., & Li, S. (2014). Internet of things in industries: A survey. *IEEE Transactions on Industrial Informatics, 10*(4), 2233–2243. https://doi.org/10.1109/TII.2014.2300753.

DeHondt, G. (2019). Legal Issues with IoT. *Fundamentals of Internet of Things for Non-Engineers*, 269–278. doi:10.1201/9780429274992-14.

Domínguez-May, R., Hernández, J. M., & Velázquez-Abunader, I. (2024). A review of dynamic optimization in aquaculture production economics. *Reviews in Aquaculture*. doi:10.1111/raq.12918.

Eduardo, M. (2017). Threats of the internet of things in a techno-regulated society: A new legal challenge of the information revolution. *The ORBIT Journal, 1*(1), 1–17. doi:10.29297/orbit.v1i1.17.

García-Poza, S., Leandro, A., Cotas, C., Cotas, J., Marques, J. C., Pereira, L. l, & Gonçalves, A. M. M. (2020). The evolution road of seaweed aquaculture: Cultivation technologies and the industry 4.0. *International Journal of Environmental Research and Public Health, 17*(18), 1–42. doi:10.3390/ijerph17186528.

Grecuccio, J., Giusto, E., Fiori, F., & Rebaudengo, M. (2020). Combining blockchain and iot: Food-chain traceability and beyond. *Energies, 13*(15). doi:10.3390/en13153820.

Guo, H., Ren, J., Zhang, D., Zhang, Y., & Hu, J. (2018). A scalable and manageable IoT architecture based on transparent computing. *Journal of Parallel and Distributed Computing, 118*, 5–13. doi:10.1016/j.jpdc.2017.07.003.

Hasnan, N. Z., & Yusoff, Y. M. (2018). Short review: Application areas of industry 4.0 technologies in food processing sector. *2018 IEEE 16th student conference on research and development, SCOReD 2018*. doi:10.1109/SCORED.2018.8711184.

Hassoun, A., Cropotova, J., Trollman, H., Jagtap, S., Garcia-Garcia, G., Parra-López, C., Nirmal, N., Özogul, F., Bhat, Z., Aït-Kaddour, A., & Bono, G. (2023). Use of industry 4.0 technologies to reduce and valorize seafood waste and by-products: A narrative review on current knowledge. *Current Research in Food Science, 6*. doi:10.1016/j.crfs.2023.100505.

Halias, A. (2021). The History of IoT: a Comprehensive Timeline of Major Events, Infographic. HQSOFTWARE. Retrieved 28 May from https://hqsoftwarelab.com/blog/the-history-of-iot-a-comprehensive-timeline-of-major-events-infographic/

Hassoun, A., Siddiqui, S. A., Smaoui, S., Ucak, İ., Arshad, R. N., Garcia-Oliveira, P., Prieto, M. A., Aït-Kaddour, A., Perestrelo, R., Câmara, José S., & Bono, G. (2022). Seafood processing, preservation, and analytical techniques in the age of Industry 4.0. *Applied Sciences (Switzerland), 12*(3). doi:10.3390/app12031703.

Hussain Dar, A., Rashid, N., Majid, I., Hussain, S., & Dar, M. A. (2020). Nanotechnology interventions in aquaculture and seafood preservation. *Critical Reviews in Food Science and Nutrition, 60*(11), 1912–1921. doi:10.1080/10408398.2019.1617232.

Islam, S. I., Ahammad, F., & Mohammed, H. (2024). Cutting-edge technologies for detecting and controlling fish diseases: Current status, outlook, and challenges. *Journal of the World Aquaculture Society, 55*(2). doi:10.1111/jwas.13051.

Ismail, S., Reza, H., Salameh, K., Kashani, Z., Hossein, & Vasefi, F. (2023). Toward an intelligent blockchain iot-enabled fish supply chain: A review and conceptual framework. *Sensors, 23*(11). doi:10.3390/s23115136.

Jagtap, S., Bhatt, C., Thik, J., & Rahimifard, S. (2019). Monitoring potato waste in food manufacturing using image processing and internet of things approach. *Sustainability (Switzerland, 11*(11). doi:10.3390/su11113173.

Jindal, F., Jamar, R., & Churi, P. (2018). Future and challenges of internet of things. *International Journal of Computer Science & Information Technology, 10*(2), 13–25.

Kalla, D., & Smith, N. (2024). Integrating Iot, AI, and big data for enhanced operational efficiency in smart factories. *Educational Administration: Theory and Practice, 30*(5), 14235–14245.

Kamarudin, A., Yap, N. K., Ali, M. A., & Phang, L. W. (2020). Lim swee, a preliminary component model for IoT. *IOP Conference Series: Materials Science and Engineering, 769*(1). doi:10.1088/1757-899X/769/1/012003.

Karunathilake, A. T., Le, S., Heo, Y., Chung, S., & Mansoor, S. (2023). The path to smart farming: Innovations and opportunities in precision agriculture. *Agriculture (Switzerland), 13*(8). doi:10.3390/agriculture13081593.

Kumar, N. M., & Mallick, P. K. (2018). The internet of things: Insights into the building blocks, component interactions, and architecture layers. *Procedia Computer Science, 132*, 109–117. doi:10.1016/j.procs.2018.05.170.

Little, A. S., Needle, C. L., Hilborn, R., Holland, D. S., & Marshall, C. T. (2015). Real-time spatial management approaches to reduce bycatch and discards: Experiences from Europe and the United States. *Fish and Fisheries, 16*(4), 576–602. doi:10.1111/faf.12080.

Martens, C. D. P., da Silva, L. F., Silva, D. F., & Martens, M. L. (2022). Challenges in the implementation of internet of things projects and actions to overcome them. *Technovation, 118*. doi:10.1016/j.technovation.2021.102427.

Mehannaoui, R., Mouss, K. N., & Aksa, K. (2023). IoT-based food traceability system: Architecture, technologies, applications, and future trends. *Food Control, 145*. doi:10.1016/j.foodcont.2022.109409.

Merrifield, M., Gleason, M., Bellquist, L., Kauer, K., Oberhoff, D., Burt, C., Reinecke, S., & Bell, M. (2019). eCatch: Enabling collaborative fisheries management with technology. *Ecological Informatics, 52*, 82–93. doi:10.1016/j.ecoinf.2019.05.010.

Mishra, R., Naik, B. K. R., Raut, R. D., & Kumar, M. (2022). Internet of Things (IoT) adoption challenges in renewable energy: A case study from a developing economy. *Journal of Cleaner Production, 371*. doi:10.1016/j.jclepro.2022.133595.

Misra, Y. D., Al-Mallahi, A., Bhullar, M. S., & Upadhyay, R. (2022). Alex martynenko, IoT, big data, and artificial intelligence in agriculture and food Industry. *IEEE Internet of Things Journal, 9*(9), 6305–6324. doi:10.1109/JIOT.2020.2998584.

Mostaccio, A., Bianco, G. M., Marrocco, G., & Occhiuzzi, C. (2023). RFID Technology for Food Industry 4.0: A Review of solutions and applications. *IEEE Journal of Radio Frequency Identification,* 7, 145–157. doi:10.1109/JRFID.2023.3278722.

Mustapha, U. F., Alhassan, A.-W., Jiang, D.-N., & Li, G.-L. (2021). Sustainable aquaculture development: A review on the roles of cloud computing, internet of things and artificial intelligence (CIA). *Reviews in Aquaculture, 13*(4), 2076–2091. doi:10.1111/raq.12559.

Noura, M., Atiquzzaman, M., & Gaedke, M. (2019). Interoperability in internet of things: Taxonomies and open challenges. *Mobile Networks and Applications, 24*(3), 796–809. doi:10.1007/s11036-018-1089-9.

Ojo, O. O., Shah, S., Coutroubis, A., Jimenez, M. T., & Ocana, Y. M. (2018). Potential impact of industry 4.0 in sustainable food supply chain environment. In *2018 IEEE international conference on technology management, operations and decisions, ICTMOD 2018* (pp. 172–177). doi:10.1109/ITMC.2018.8691223.

Pal, A., & Kant, K. (2018). IoT-based sensing and communications infrastructure for the fresh food supply chain. *Computer, 51*(2), 76–80. doi:10.1109/MC.2018.1451665.

Popa, A., Hnatiuc, M., Paun, M., Geman, O., Hemanth, D. J., Dorcea, D., & Le Hoang Son, S. G. (2019). An intelligent IoT-based food quality monitoring approach using low-cost sensors. *Symmetry, 11*(3), 374. doi:10.3390/sym11030374.

Popovic, T., Drajicc, D., Ogrinc, N., Terro, C., & Urosevic, V. (2024). Implementing an IoT system for sea to fork transparency and consumer engagement. *2024 28th International conference on information technology, IT 2024*. doi:10.1109/IT61232.2024.10475712.

Provenance (2016). From shore to plate: Tracking tuna on the blockchain,Provenance pilot blockchain technology for tracing yellowfin and skipjack tuna fish in Indonesia from catch to consumer," PROVENANCE, 15 July, 2016. [Online]. Available: https://legacy.provenance.org/tracking-tuna-on-the-blockchain#overview

Qiu, T., Chi, J., Zhou, X., Ning, Z., Atiquzzaman, M., & Oliver Wu, D. (2020). Edge computing in industrial internet of things: Architecture, advances and challenges. *IEEE Communications Surveys and Tutorials, 22*(4), 2462–2488. doi:10.1109/COMST.2020.3009103.

Rawajbeh, M. A., Alzu'bi, S., & Alkhatib, A. (2023). IoT-Paradigm: Evolution challenges and proposed solutions. In *Proceedings of 2023 IEEE international smart cities conference, ISC2 2023*. doi:10.1109/ISC257844.2023.10293646.

Riggins, F. J., & Fosso Wamba, S. (2015). Research directions on the adoption, usage, and impact of the internet of things through the use of big data analytics. In *Proceedings of the Annual Hawaii international conference on system sciences* (pp. 1531–1540). doi:10.1109/HICSS.2015.186.

Rosaline, N., & Sathyalakshimi, S. (2019). IoT based aquaculture monitoring and control system. *Journal of Physics: Conference Series, 1362*(1). doi:10.1088/1742-6596/1362/1/012071.

Rowan, N. J. (2023). The role of digital technologies in supporting and improving fishery and aquaculture across the supply chain—Quo Vadis? *Aquaculture and Fisheries, 8*(4), 365–374. doi:10.1016/j.aaf.2022.06.003.

Sehrawat, D., & Gill, N. S. (2019). Smart sensors: Analysis of different types of IoT sensors. In *Proceedings of the international conference on trends in electronics and informatics, ICOEI 2019* (pp. 523–528). doi:10.1109/ICOEI.2019.8862778.

Senturk, S., Senturk, F., & Karaca, H. (2023). Industry 4.0 technologies in agri-food sector and their integration in the global value chain: A review. *Journal of Cleaner Production, 408*. doi:10.1016/j.jclepro.2023.137096.

Serpanos, D., & Wolf, M. (2017). Internet-of-things (IoT) systems: Architectures, algorithms, methodologies. *Internet-of-Things (IoT) Systems: Architectures, Algorithms, Methodologies*, 1–95. doi:10.1007/978-3-319-69715-4.

Sikimic, M., Amovic, M., Vujovic, V., Suknovic, B., & Manjak, D. (2020). An overview of wireless technologies for IoT network. In *2020 19th international symposium Infoteh-Jahorina, Infoteh 2020—Proceedings*. doi:10.1109/INFOTEH48170.2020.9066337.

Singh, B., & Kaunert, C. (2024). Integration of cutting-edge technologies such as Internet of Things (IoT) and 5G in health monitoring systems: A comprehensive legal analysis and futuristic outcomes. *GLS Law Journal, 6*(1), 13–20. doi:10.69974/glslawjournal.v6i1.123.

Stentiford, N., Peeler, S., Small, F., Vlak, J., Morado, M., Lotz, B., Behringer, H., & Lightner (2012). Disease will limit future food supply from the global crustacean fishery and aquaculture sectors. *Journal of Invertebrate Pathology, 110*(2), 141–157. doi:10.1016/j.jip.2012.03.013.

Stojanovic, N., & Chaudhary, S. (2023). Real-time water quality monitoring in aquaculture using IoT sensors and cloud-based analytics. *Research Journal of Computer Systems and Engineering, 4*(2), 174–187. doi:10.52710/rjcse.86.

Subash, A., Ramanathan, H. N., & Šostar, M. (2024). From catch to consumer: Enhancing seafood processing management with Industry 4.0 innovations. *Discover Food, 4*(1). doi:10.1007/s44187-024-00115-6.

Tolentino-Zondervan, F., Ngoc, P. T. A., & Roskam, J. L. (2023). Use cases and future prospects of blockchain applications in global fishery and aquaculture value chains. *Aquaculture, 565*. https://doi.org/10.1016/j.aquaculture.2022.739158.

Tyagi, H., & Kumar, R. (2020). Cloud computing for IoT. *Internet of Things (IoT): Concepts and Applications*, 25–41. https://doi.org/10.1007/978-3-030-37468-6_2.

Ubina, N. A., & Cheng, S.-C. (2022). A review of unmanned system technologies with its application to aquaculture farm monitoring and management. *Drones, 6*(1). https://doi.org/10.3390/drones6010012.

Verdouw, C., Wolfert, S., & Tekinerdogan, B. (2016). Internet of things in agriculture. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 11*. https://doi.org/10.1079/PAVSNNR201611035.

Vollen, A., & Haddara, M. (2019). IoT aboard coastal vessels: A case study in the fishing industry. *Lecture notes in computer science (Including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics), 11673*, 163–177. https://doi.org/10.1007/978-3-030-27192-3_13.

Zhang, H., Li, B., Karimi, M., Saydam, S., & Hassan, M. (2023). Recent advancements in iot implementation for environmental, safety, and production monitoring in underground mines. *IEEE Internet of Things Journal, 10*(16), 14507–14526. https://doi.org/10.1109/JIOT.2023.3267828.