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AQUALINK

IOT platform for smart aquaculture
In the context of industry 4.0

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Thanks and Apprecitation

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Thanks and Appreciation

FENIK KHALED

Abstract

The health and productivity of aquatic creatures in aquaculture systems depend on maintaining ideal water quality conditions. Aquaculture significantly influences seafood production worldwide. Conventional monitoring techniques can be lengthy, infrequent, and lack the promptness necessary to prevent and alleviate unfavorable circumstances. This study proposes a novel method for real-time water quality monitoring in aquaculture, utilizing cloud-based data and Internet of Things (IoT) sensors. Strategically positioned IoT sensors within aquaculture facilities continuously collect information on key water quality factors such as temperature, pH levels. Real-time monitoring enables aquaculturists to quickly detect deviations from optimal conditions, reducing the risk of disease outbreaks and aquatic species mortality. Additionally, the system integrates a comprehensive management platform that tracks information on feed, medication, and incidents, stored in a detailed database. To enhance the development and testing phases, we employed the Wokwi simulator, which allowed us to simulate and validate the functionality of sensors and actuators before physical deployment. This approach offered several advantages, including cost-effectiveness by reducing hardware expenses during prototyping and minimizing risks associated with potential hardware failures in real-world scenarios. The use of the Wokwi simulator ensured that our IoT solution met performance and reliability standards, laying a solid foundation for its successful deployment and operation in aquaculture settings.

Keywords: Smart aquaculture, Industry 4.0, IoT, fish monitoring, sustainable development.

الملخص

تعتمد صحة وإنتاجية الكائنات المائية في أنظمة تربية الأحياء المائية على الحفاظ على ظروف جودة المياه المثلى. تؤثر تربية الأحياء المائية بشكل كبير على إنتاج المأكولات البحرية عالميًا. يمكن أن تكون تقنيات المراقبة التقليدية طويلة الأمد وغير متكررة وتفتقر إلى السرعة اللازمة لمنع وتخفيف الظروف غير المواتية. تقترح هذه الدراسة طريقة جديدة لمراقبة جودة المياه في الوقت الفعلي في تربية الأحياء المائية باستخدام البيانات المستندة إلى السحابة وأجهزة استشعار إنترنت الأشياء . تجمع أجهزة الاستشعار الخاصة بإنترنت الأشياء والموجودة بشكل استراتيجي داخل مرافق تربية الأحياء المائية معلومات مستمرة حول العوامل الرئيسية لجودة المياه مثل درجة الحرارة ومستويات الحموضة . تمكن المراقبة في الوقت الفعلي مربي الأحياء المائية من اكتشاف الانحرافات عن الظروف المثلى بسرعة، مما يقلل من خطر انتشار الأمراض ونفوق الأنواع المائية. بالإضافة إلى ذلك، يدمج النظام منصة إدارة شاملة تتعقب المعلومات حول التغذية والأدوية والحوادث، المخزنة في قاعدة بيانات مفصلة. لتعزيز مراحل التطوير والاختبار، استخدمنا المحاكي واكو الذي سمح لنا بمحاكاة والتحقق من وظائف أجهزة الاستشعار والمشغلات قبل النشر الفعلي. قدم هذا النهج عدة مزايا، بما في ذلك التكلفة الفعالة عن طريق تقليل نفقات الأجهزة أثناء النمذجة وتقليل المخاطر المرتبطة بفشل الأجهزة المحتمل في السيناريوهات الواقعية. ضمان استخدام محاكي واكو أن حل إنترنت الأشياء الخاص بنا يفي بمعايير الأداء والموثوقية، مما يضع أساسًا قويًا لنشره ونجاح تشغيله في بيئات تربية الأحياء المائية.

الكلمات المفتاحية: تربية الأحياء المائية الذكية، الصناعة ٤.٠، إنترنت الأشياء، مراقبة الأسماك، التنمية المستدامة.

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List of abbrreviation:

IOT: Internet Of Things

DO: Dissolved Oxygen

DB: Database

AI: Artificial Intelligence

ML: Machine Learning

CV: Computer Vision

Chapter 01

1 General Introduction

1.1 Introduction

Aquatic organisms, like all living beings, thrive under specific environmental conditions. The growth and health of aquatic life, and thus the success of aquaculture production, are largely dependent on water quality . Effective water quality management is one of the most critical challenges in aquaculture, as it directly impacts the health and growth rate of fish. Ponds with good water quality yield healthier and more abundant fish compared to those with poor water quality 2%. However,managing water quality in aquaculture is challenging due to the technical knowledge required to understand and monitor the physio-chemical and biological properties of water, such as temperature, pH, turbidity, salinity, ammonia, and oxygen levels. This expertise is often not readily available to fish farmers, especially in developing countries.

Traditional methods of water quality management rely heavily on the farmer 39% ;intuition and periodic testing, which are labor-intensive and delay response times. Hand-held test kits, while an improvement, still depend on manual processes and do not fully address the challenges.

Consequently, water quality issues are often detected only after they have negatively impacted the fish stock, leading to high mortality rates and slow growth, thereby reducing productivity and profitability.

The advent of advanced technologies, such as electronic sensors, embedded systems, smart internet- enabled devices, automation, and artificial intelligence, offers new opportunities for innovation in agriculture. These technologies, collectively known as smart agriculture, leverage IoT, machine learning, real-time data collection, and big data analytics to address longstanding challenges in agriculture and significantly enhance productivity. Industry 4.0, also called the Fourth Industrial Revolution, consists of the most recent stage of industrialization in which smart devices are used to ensure the physical-digital connection of the components that make up the production flow to guarantee a fully optimized and integrated process. Some technological trends in this phase that can act as key tools for the production of more sustainable food are the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), computer vision (CV), and optimized sensors . The feedback to an automated system of the quantitative values of process' key parameters, collected using sensors, enables optimized performance that guarantees a high-quality product .

The review of related works reveals advancements in IoT-based aquaculture, showcasing wireless sensor networks and smart devices for real-time water quality monitoring. Studies by Yang et al. (2012), Simbeye amp; Yang (2014), and Liu et al. (2016) highlight the improvements in accuracy and efficiency.

However, these works often lack comprehensive management systems and robust databases, which our research aims to address by integrating IoT with detailed data management for enhanced decision-making and efficiency in aquaculture. Additionally, our use of a simulator to test sensors and actuators provides a cost-effective and risk-free environment for validating the system, ensuring reliability and performance before real-world deployment.

This research investigates how IoT and smart automation technology can be effectively applied to measure, monitor, and control water quality parameters in fish farming, and how an IoT-based water quality management system can improve productivity in aquaculture by reducing fish mortality rates and promoting faster growth. To address these questions, the main objectives are to design and implement an IoT sensor network and control module to measure and monitor selected water quality parameters, transmitting the data to a cloud database;

to develop and implement algorithms to analyze the data and recommend or implement actions using suitable actuators connected to the system; to test and evaluate the performance of the proposed system; and to integrate a farm management system to manage and track information on feed, medication, and purchases, using the collected data to enhance decision-making and operational efficiency.

Additionally, the system includes a comprehensive database that stores detailed information on water quality, fish health, feed, incidents, and medication. This database not only aids in immediate decision-making but also serves as a valuable resource for future data analysis and machine learning applications. Furthermore, the use of a simulator to test the sensors and actuators before actual deployment provides significant advantages, allowing for troubleshooting and refinement of the system in a controlled environment, thus ensuring reliability and accuracy in real-world applications.

1.2 Motivation

The Aqualink system offers an innovative solution for aquaculture by harnessing the power of Internet of Things (IoT) technology. The system provides precise control over the aquatic environment, enhancing productivity, reducing costs, and minimizing environmental impact.

The system relies on a network of internet-connected sensors that collect data about the aquatic environment, such as water temperature, oxygen levels, and pH levels. This data is analyzed using AI algorithms, enabling farmers to gain insights into the health of the fish and the condition of the aquatic environment.

Aqualink helps predict risks such as diseases and fish mortality, allowing farmers to take quick preventive actions. It also provides accurate and measurable data that enables farmers to make informed decisions to improve fish farming practices.

1.3 Context and Problematic

Monitoring water quality in aquaculture is a critical challenge. The key parameters for water quality include temperature, pH, turbidity, and dissolved oxygen levels. These parameters directly impact the health and productivity of fish. Unregulated changes in temperature or pH, increased turbidity, and decreased dissolved oxygen levels can stress fish and increase their susceptibility to diseases, significantly reducing productivity.

Traditional water quality monitoring techniques rely on manual methods, which involve periodic data collection and analysis. These methods have significant limitations, often leading to delays in problem detection and decision-making. Moreover, these methods require considerable time and effort from skilled labor, which may be scarce in some instances[1].

Given these challenges, there is a pressing need to adopt automated and continuous solutions for water quality monitoring in aquaculture. Internet of Things (IoT) technologies offer effective solutions to this problem, enabling real-time, continuous monitoring of water quality and providing accurate, instant data that supports swift and effective decision-making. By adopting these technological solutions, fish health can be significantly improved, and productivity can be increased, enhancing sustainability in the field.

1.4 Theoretical background

Aquaculture, or aquafarming, is a vital agricultural sector that significantly enhances global food supplies by cultivating fish, shellfish, mollusks, and aquatic plants in controlled environments or in seas and ponds. The origins of this practice date back to ancient times, and while aquaculture techniques have evolved over time, they still face significant challenges, especially in the absence of advanced technology. To address these challenges, the integration of modern technology into aquaculture is essential. Such technologies provide solutions for effective monitoring and management of aquatic environments, predicting potential issues, and resolving them proactively. This integration enhances productivity and sustainability, ensuring the health and growth of aquatic organisms[2].

With a growing emphasis on environmental conservation and sustainable development, there is increasing interest in smart aquaculture methods. Smart aquaculture, the farming of aquatic organisms using intelligent systems, offers remarkable opportunities for research and innovation. These systems leverage a variety of advanced technologies, including sensors for water quality monitoring, actuators for controlling environmental systems, communication gateways for data transfer, and cloud-based analytics platforms for data analysis and decision-making. This interactive and dynamic approach allows for real-time monitoring and automatic adjustment of environmental conditions, significantly improving productivity and efficiency.[3].

Smart aquaculture leverages a variety of advanced technologies, including sensors to monitor water quality, actuators to control environmental systems, communication gateways to transfer data between devices and the cloud, and cloud-based analytics platforms to analyze data and make decisions. This interactive and dynamic approach allows for the real-time monitoring and automatic adjustment of environmental conditions, significantly improving the productivity and efficiency of aquaculture systems[4].

Smart aquaculture holds strategic importance in addressing growing food challenges and meeting the needs of the increasing global population, as providing pure and renewable food sources is vital for sustainable development. This article provides an overview of the evolution of smart aquaculture, highlighting its economic and environmental significance, supported by recent research and scientific references in the field.[5]

1.4.1 Smart Aquaculture

Smart aquaculture refers to the application of advanced technologies such as sensors, data analytics, and automation in the farming of aquatic organisms like fish, crustaceans, and mollusks. These technologies enable real-time monitoring and control of various parameters such as water quality, feeding regimes, and environmental conditions, thereby optimizing production efficiency, reducing resource wastage, and enhancing sustainability[6]. In smart aquaculture systems, sensors are deployed throughout aquaculture facilities to collect data on parameters such as water temperature, pH levels, dissolved oxygen, and ammonia levels. This data is then transmitted to a centralized system where it is analyzed in real-time. Based on this analysis, automated systems can adjust factors like water flow, oxygenation, and feeding schedules to maintain optimal conditions for the health and growth of the aquatic organisms. The integration of data analytics allows for predictive modeling and optimization of production processes, enabling farmers to make informed decisions to maximize yields while minimizing environmental impact. Additionally, smart aquaculture systems often utilize remote monitoring and control capabilities, allowing farmers to manage their operations from anywhere with an internet connection. smart aquaculture represents a cutting-edge approach to aquaculture management that leverages technology to improve productivity, sustainability, and profitability in the farming of aquatic organisms[7].

Figure 1: Aquaculture Farm[8].

1.4.2 Definition

Smart aquaculture is the application of advanced technologies and systems to make the cultivation of aquatic organisms more efficient and sustainable[9]. The goal of smart aquaculture is to improve the management of water and environmental resources, increase productivity, reduce risks, and enhance environmental sustainability. This includes the use of technologies such as:

Internet of Things (IoT):

Utilizing internet-connected sensors and tools to collect real-time data on water quality, temperature, oxygen levels, and fish health.

Big Data and Data Analytics:

Employing big data analytics to analyze trends and patterns and provide accurate forecasts that assist in making informed decisions regarding farm management.

Robotics and Automation:

Using robots and automation to perform routine tasks with precision and efficiency, such as feeding, cleaning, and monitoring[10]. Remote Control and

Software Management:

Managing and monitoring fish farms remotely using advanced software that provides user-friendly interfaces and comprehensive real-time information.

Sustainable Energy:

Utilizing renewable energy sources and energy-efficient systems to reduce the carbon footprint of aquaculture. Integrated Production Systems: Integrating different production systems such as aquaponics, which combines fish farming and plant cultivation in an integrated system that enhances sustainability [11].

1.4.3 History of smart aquaculture

Smart aquaculture, also known as fish farming, is the cultivation of aquatic organisms such as fish, crustaceans, mollusks, and aquatic plants. It has a long and varied history that dates back thousands of years. Below is an overview of the history of aquaculture[12]:

Ancient Beginnings:

Early Practices: The earliest known instances of aquaculture can be traced back to ancient China around 2500 BCE, where the farming of carp was practiced. The Chinese were the first to document techniques for breeding fish and managing ponds.
Egypt and Rome: In Egypt, records from around 2000 BCE indicate the use of aquaculture for raising tilapia. The Romans also engaged in aquaculture, particularly in coastal lagoons and ponds, to cultivate oysters and fish[13].

Middle Ages and Renaissance:

Europe: During the Middle Ages, Europe saw the rise of monastic fish farming, particularly in ponds constructed by monks to provide a steady supply of fish for religious feasts and fasting periods.
Japanese Innovations: In Japan, aquaculture practices developed in the 8th century with the cultivation of seaweed, carp, and other fish species in controlled environments.[14]

19th and 20th Centuries:

Modern Aquaculture: The modern era of aquaculture began in the 19th century with advancements in breeding techniques and the establishment of hatcheries. Notably, the first modern fish hatchery was established in 1853 in the United States.
Technological Advances: The 20th century saw significant technological advancements in aquaculture, including the development of artificial feeds, disease control methods, and the intensification of production systems[15].

Contemporary Aquaculture

Global Expansion: Aquaculture has expanded globally, becoming a significant contributor to food security and the global economy. Today, major producers include China, Southeast Asia, Norway, and Chile.
Sustainability Challenges: Contemporary aquaculture faces challenges such as environmental impact, sustainability, and the need for improved management practices to ensure the health of aquatic ecosystems and communities.[16]

1.4.4 Benefits of smart Aquaculture

The role of smart aquaculture encompasses several crucial aspects that positively impact the aquaculture industry and the surrounding environment[17]. Here are some key roles of smart aquaculture:

- Increased productivity: Smart aquaculture helps to enhance resource utilization efficiency and improve production processes, leading to increased farm productivity and the provision of more food resources[76].
- Cost reduction: Through the use of technology and automation, production costs can be reduced, and resource management efficiency can be improved, contributing to greater profits for farmers.
- Product quality improvement: Smart aquaculture helps maintain product quality and safety through continuous monitoring of the fish farming environment and the implementation of effective health measures.
- Environmental sustainability: Smart aquaculture promotes environmental sustainability by reducing the environmental impact of production operations and improving water resource management.

- Providing a conducive environment for marine life: Smart aquaculture contributes to providing a suitable and sustainable environment for marine life, helping to protect biodiversity and conserve endangered species[18].

- Enhancing food security: Smart aquaculture contributes to providing reliable and sustainable food sources, thus enhancing food security at both local and global levels[18].

1.4.5 Smart Aquaculture Technologies

The future of smart aquaculture holds tremendous promise for addressing many challenges faced by the aquaculture industry. Here are some key aspects of its future:[19][24]

Advanced Monitoring and Data Analytics:
Precision aquaculture will heavily rely on advanced monitoring technologies such as sensors, underwater cameras, and drones to collect real-time data on water quality, fish behavior, and environmental conditions. This data will be analyzed using artificial intelligence and machine learning algorithms to optimize feeding regimes, detect diseases early, and improve overall farm management practices[19].

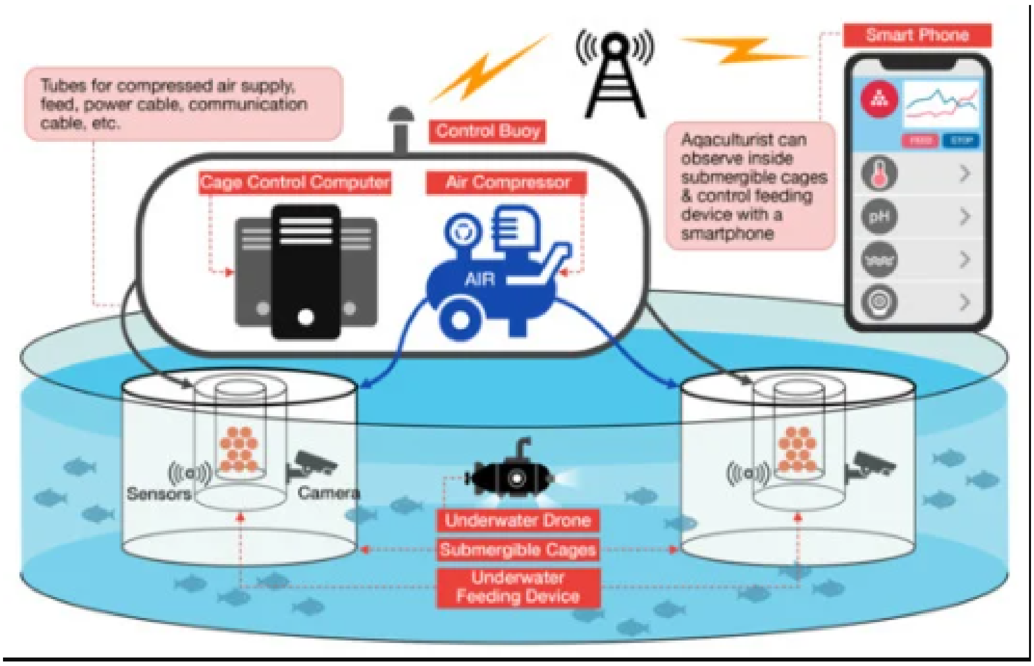

Figure 2: Diagram of Smart Aquaculture System Using monitoring technique [20].

Automation and Robotics: Automation will play a significant role in precision aquaculture, with the development of robotic feeders, autonomous underwater vehicles (AUVs), and automated sorting systems. These technologies will help reduce labor costs, improve efficiency, and minimize human intervention in fish farms[21].

Integrated Farm Management Systems: Smart aquaculture will integrate various farm management systems, including feeding systems, water treatment systems, and environmental control systems, into a unified platform. This integrated approach will enable farmers to monitor and control all aspects of their operations from a single interface, improving efficiency and productivity.

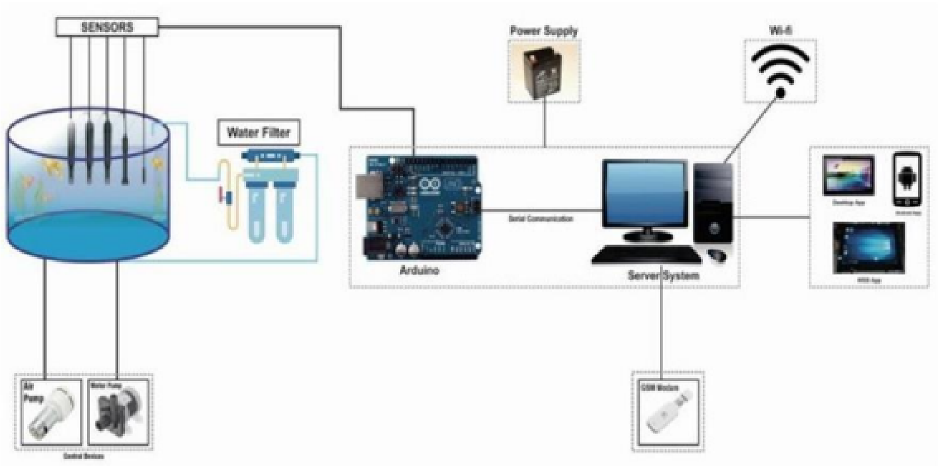

Figure 3: Block diagram of the smart aquaculture systems[22].

Closed-Loop Systems and Recirculating Aquaculture: Closed-loop systems, such as recirculating aquaculture systems (RAS), will become more prevalent in precision aquaculture. These systems recycle water and waste, minimizing environmental impacts and reducing the risk of disease outbreaks. They also allow for more precise control over water quality parameters, leading to higher stocking densities and increased production yields.

Decision support systems: These systems can use data from sensors and other sources to provide farmers with real-time insights into the health of their fish and the performance of their aquaculture operation.

1.5 Objectives

The main objective of this thesis is to design and implement an IoT-based water quality management system for aquaculture that can significantly improve productivity by reducing fish mortality rates and promoting faster growth. The specific objectives are:
1. Design and Implementation of an IoT Sensor Network: - Develop a network of IoT sensors and control modules to measure and monitor key water quality parameters such as temperature, pH, turbidity, salinity, ammonia, and oxygen levels. - Ensure reliable data transmission from sensors to a centralized cloud database.
2. Use the analysis to recommend or automatically implement actions through connected actuators, adjusting PH levels.
3. Testing and Evaluation: - Conduct comprehensive testing of the IoT system to evaluate its performance in real-world aquaculture environments. - Utilize a simulator for initial testing of sensors and actuators to validate

the system in a cost- effective and risk-free manner, ensuring reliability before deployment.
4. Integration of Farm Management System: - Integrate a comprehensive farm management system to track and manage feed, medication, incidents, and overall health of the fish. - Develop detailed database tables to store and organize data, enhancing decision-making and operational efficiency.

1.6 Outline of the Thesis

This Thesis is structured in 6 chapters:
Chapter02:
This chapter provides an overview of smart aquaculture, including its definition, benefits, and significance. It discusses how smart aquaculture has evolved into a crucial component of global food production and economic activity, tracing its origins back to ancient civilizations. The chapter outlines the process of cultivating various aquatic organisms in controlled environments and emphasizes the importance of precise control over environmental factors for the success of smart aquaculture. Furthermore, it highlights the role of aquaculture and smart aquaculture in providing high-quality protein-rich food sources, contributing to food security, generating income and employment opportunities, and preserving the aquatic environment.
Chapter03:
This chapter discusses the importance and evolution of Internet of Things (IoT) technology and its numerous benefits in various fields, such as improving efficiency, reducing errors, enhancing remote control, and fostering innovation. The chapter also explores the role of IoT in improving water quality in aquaculture, and how sensor devices and data analysis can be used to enhance aquatic environmental conditions and promote the success of aquaculture. In general, this chapter provides a comprehensive overview of Internet of Things technology and its growing impact on many aspects of our lives.
Chapter04:
This chapter provides an overview of the use of Internet of Things (IoT) technology in aquaculture. It discusses the benefits and potential applications of IoT in this field, and reviews some relevant studies that illustrate how IoT is used to improve aquaculture practices.
This chapter also discusses the design that illustrates the program's operation principle, providing a detailed explanation of its creation process and the tools used in its development.
Chapter05:
General Conclusion: The chapter's conclusion emphasizes the importance of the smart system in aquaculture. It highlights some key points that have been emphasized.

Chapter 02

2 Smart Aquaculture and IOT

2.1 Internet of Things (IoT)

In our current era, the Internet of Things (IoT) is considered one of the most impactful technological advancements on daily human life and operations. This technology has brought about a transformation in how things communicate with each other, enabling remote control and monitoring of objects by connecting them to the internet. The benefits of IoT extend to accelerating various industrial and commercial processes, organizing them, enhancing efficiency, reducing errors, and making them more accessible.[23]
The Internet of Things represents a technological revolution that is key to the future of computing and communications.[24] The term "Internet of Things" first emerged in 1997 in a report issued by the International Telecommunication Union (ITU) titled "Challenges to the Network." However, credit for coining the term is attributed to Kevin Ashton in 1999 in an RFID Journal article.
Imagine a world where network-connected devices communicate with each other and share information about the physical world via the Internet.
In 2005, the name "Internet of Things" was officially adopted. Soon, this term came to refer to a vast network of physical devices embedded with sensors and communication devices that enable the collection, processing, and wireless transmission of data.
The Internet of Things represents a revolution in how we interact with the world around us. It opens the door to tremendous possibilities in areas such as:

Smart Control: Remote control of devices and equipment, such as lighting, heating, and ventilation systems.

- Monitoring: Surveillance of environmental conditions, such as temperature and humidity levels.
- Data Collection: Gathering data from various sources and analyzing it to make better decisions.
- Automation: Automating repetitive tasks, such as turning on lights or operating home appliances.
- Innovation: Stimulating innovation in various fields, such as healthcare, transportation, and manufacturing.

The Internet of Things is one of the most significant technological developments in our current era. It is changing the way we live, work, and interact with the world around us. While this technology is still in its early stages of development, its potential is vast and promising[23][7].
IOT is a technology that enables various objects to communicate and interact intelligently and seamlessly, opening the door to multiple applications that contribute to improving daily life, enhancing efficiency, and fostering innovation in a wide range of fields.[25]

2.1.1 Definition

The Internet of Things (IoT) is a revolutionary technology that embeds physical devices with sensors and software, enabling them to connect and interact with each other and the internet.
According to the Oxford English Dictionary, IoT represents "a proposal for extending the Internet beyond conventional devices by embedding chips and sensors into everyday objects and allowing them to communicate with one another and exchange data" ([Oxford University Press, 2018]). IoT goes beyond a mere technical definition; it embodies a profound transformation in how we interact with the world around us. It bridges the physical and digital worlds, allowing us to collect, analyze, and understand data in unprecedented ways. IoT

relies on four fundamental pillars: devices, connectivity, data, and analytics. Devices generate vast amounts of data that are used to understand their characteristics and interactions with the surrounding environment. This data is then analyzed using artificial intelligence techniques to extract valuable insights and make intelligent decisions.

IoT is revolutionizing various fields, including healthcare, smart cities, industry, agriculture, and smart homes. Despite its immense potential, IoT faces challenges such as security, privacy, interoperability, and standardization.

2.1.2 The principle of Internet of Things (IoT)

The principle of operation of an Internet of Things (IoT) engine relies on integrating smart devices with their surrounding environment and with each other through the internet or other wireless networks. The primary goal of an IoT engine is to collect, analyze, and utilize data for making intelligent decisions or executing specific activities based on this data.

To achieve this goal, physical devices are equipped with a set of sensors, controllers, and communication modules that enable them to gather data from their surrounding environment. This data is then sent to a cloud platform or server for storage and processing using advanced data analysis techniques such as artificial intelligence and machine learning.

After the data is processed, intelligent decisions are made or specific commands are executed.

In general, the principle of operation of an IoT engine relies on communication between connected devices and gathering data from their surrounding environment, processing this data for insights and analytics, and using this information to make intelligent decisions or execute specific commands automatically[26].

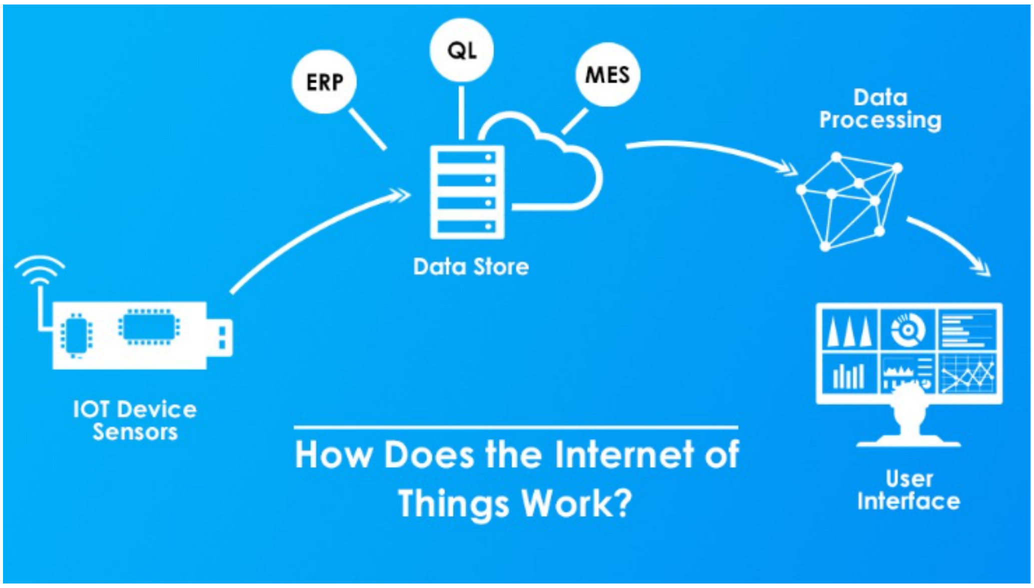

Figure 4: diagram explaining the working principle of (IoT)

2.1.3 Characteristics of Effective IOT

Effective IoT systems go beyond just connecting devices. Here are some key characteristics that define a well-designed IoT system:

- **Connectivity:**

  The foundation of any IoT system is reliable and secure data exchange between devices. This involves choosing appropriate communication protocols (WiFi, Bluetooth, cellular) that ensure data integrity and encryption for protection against cyber threats.[27]

- **Interoperability:** Standardized Protocols Effective IoT systems enable devices from different manufacturers to communicate seamlessly. This requires adherence to standardized data formats and communication protocols to ensure devices can understand each other's data.

- **Scalability:** As the number of connected devices increases, the system should be able to handle the growing data volume and network traffic. Scalable architectures ensure efficient resource allocation and maintain performance even with a significant rise in connected devices.It means that IoT devices should be designed so that they can be easily scaled up or down according to demand.

- **Security:** Security is paramount in IoT. Measures like secure device authentication, data encryption throughout its lifecycle (at rest, in transit), and robust intrusion detection mechanisms are crucial to safeguard against cyberattacks.

- **Data Management:** The true value of IoT lies in its data. Effective systems enable real-time data processing and analysis to extract meaningful insights. This can involve edge computing (processing data at the device level) for faster response times and efficient use of cloud resources.

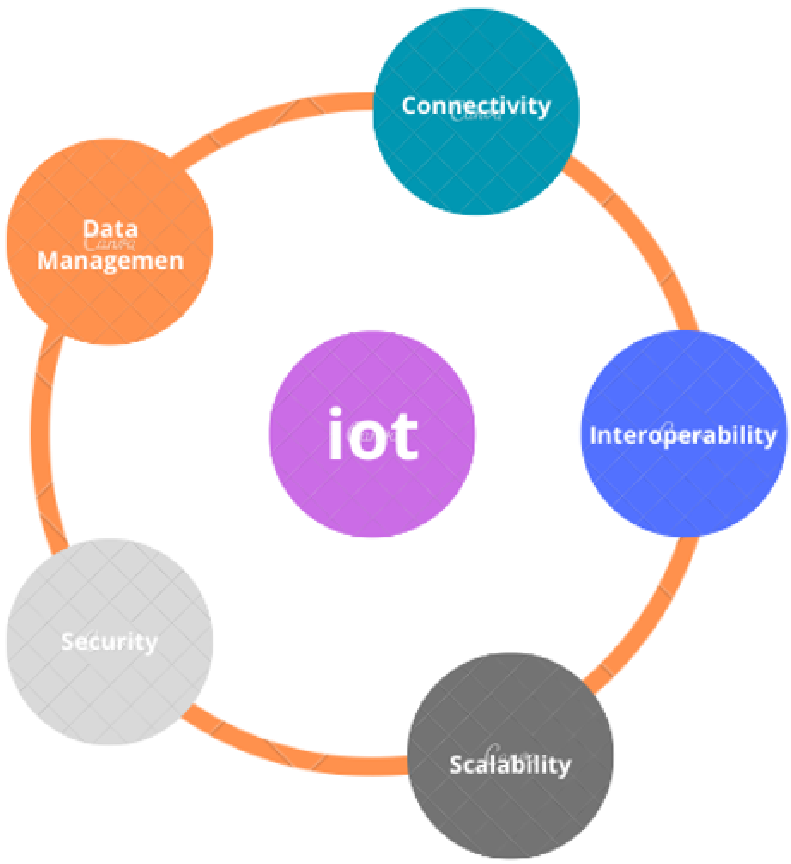

Figure 5: Characteristics of IOT

2.1.4 Type of IOT:

The world of IoT can be vast, and there are different ways to categorize its types. For example, we adopt this method:

- **By Application Domain:**
  - Consumer IoT (CIoT): This category focuses on devices used by individuals in everyday life. Examples include smart speakers, fitness trackers, smart thermostats, connected appliances, and wearable tech.
  - Industrial IoT (IIoT): Also known as the Industrial Internet of Things, this domain involves interconnected devices used in industrial settings. Examples include sensors for monitoring machinery performance, predictive maintenance systems, asset tracking in logistics, and industrial automation equipment.
  - Commercial IoT: This category encompasses applications in various commercial sectors like healthcare, retail, and transportation. Examples include smart building management systems, connected medical devices for remote monitoring, and intelligent inventory management in retail.
  - Infrastructure IoT (IIoT): This focuses on interconnected devices used to manage critical infrastructure like power grids, water distribution systems, and transportation networks. Examples include smart meters for energy management, traffic management systems, and environmental monitoring sensors.
- **By Functionality:**
  - Monitoring and Sensing: These devices collect data from the environment, such as temperature, pressure, or motion. Examples include environmental sensors in agriculture, wearables for health monitoring, and security cameras.
  - Control and Automation: These devices can influence their surroundings based on collected data or user commands. Examples include smart thermostats that adjust temperature, automated watering systems in agriculture, and connected lighting systems.
  - Identification and Tracking: These devices help track the location or status of objects or people. Examples include asset tracking tags in logistics, RFID tags for inventory management, and GPS trackers for vehicles.
  - Connectivity and Communication: These devices facilitate communication between different parts of an IoT system. Examples include gateways that connect devices to the cloud, routers for data transmission, and communication modules within devices.
  - Understanding these classifications can help you identify the specific types of IoT devices and applications relevant to your interests

2.1.5 Requirement of IOT:

The basic requirements for successful implementation of the Internet of Things (IoT) are:

Meeting Dynamic Resource Demand: The Internet of Things (IoT) is characterized by a vast number of connected devices that require dynamic resources, such as bandwidth, data processing, and storage. The IoT infrastructure must be adaptable to these changing requirements, ensuring smooth and timely provision of necessary resources[28]

Responding to Real-Time Needs: Many IoT applications require real-time data processing and analysis, such as monitoring and control systems. The IoT infrastructure must be able to meet these requirements, providing high responsiveness and reducing latency.

Accommodating Exponential Growth of Demand: A tremendous increase in the number of devices connected to IoT networks is expected in the coming years. The infrastructure must be scalable to meet this rapid growth, ensuring continued efficient service delivery.

Providing Suitable Applications: The success of IoT relies on the availability of applications that meet users' needs in various fields such as healthcare, agriculture, and manufacturing. Emphasis should be placed on developing innovative applications that add value to users and contribute to problem-solving and efficiency improvement.

Ensuring Data Protection and User Privacy: Data security and user privacy are major concerns in IoT, given the handling of vast amounts of sensitive data. Best security practices must be followed to protect data from unauthorized access and cyber attacks, while ensuring compliance with laws and regulations regarding user privacy.

Improving Power Consumption Efficiency: Efficient energy consumption is essential to ensure the sustainability of IoT projects, especially with the proliferation of battery-powered embedded devices. Devices, software, and applications should be designed and implemented in a way that conserves and reduces energy consumption.

Executing Applications Near End Users: In some cases, IoT applications require data processing and analysis near end users to reduce latency and improve performance. This can be achieved through the use of decentralized cloud computing or edge computing technologies.

Access to an Open and Interoperable Cloud System: The IoT system should be compatible with various cloud platforms and allow open access to data. This facilitates easy integration between devices and applications, preventing reliance on a single cloud provider.

In another study, there are three fundamental components required for seamless IoT computing:

Hardware: This is the physical foundation of the IoT system, where various devices like sensors, actuators, cameras, and communication modules capture and exchange data.

Middleware: This acts as the brain of the operation. It provides storage, processing power, and analytical tools to handle the data collected by the hardware. Cloud computing and big data analytics capabilities often come into play here.

Presentation: This is all about making sense of the data. User-friendly visualization and interpretation tools are crucial for presenting the information in a way that's easily understandable depending on the application.

2.1.6 Architecture of IOT

The interconnectedness of the objects in the network is a crucial prerequisite for the Internet of Things. IoT system architecture, which links the real and virtual worlds, must ensure IoT's functionality. Networking, communication, procedures, and other elements are all part of the design of an Internet of Things architecture. When creating the architectural design of IoT, device operability, scalability, and extensibility should all be taken into account. IoT design needs to be flexible in order to enable dynamic device interaction and communication since objects may move and must communicate with one another in real-time. Furthermore, IoT ought to be varied and decentralized[29].

In this Internet of Things architecture system consists of main components:

- **Sensors:**
  Sensors are a fundamental part of Internet of Things (IoT) systems, collecting data from the surrounding environment and converting it into signals that can be processed and analyzed by intelligent systems. [30]presents more information about sensors:

  Temperature Sensors: Used to measure the ambient temperature. They operate using materials that change their electrical properties with temperature variations, such as electronic thermometers.
  Dissolved Oxygen Sensors: Measure the amount of dissolved oxygen in water, which is a key indicator of water quality. They rely on electrochemical or optical techniques.
  Humidity Sensors: Measure the level of humidity in the air or soil. They use sensing materials that change their electrical resistance with humidity changes.
  Pressure Sensors: Measure atmospheric pressure or the pressure within fluids and gases. They depend on materials that alter their resistance or capacitance with pressure changes.
  Motion Sensors: Detect movement and acceleration, used in security, surveillance, and wearable devices. They use technologies such as gyroscopes and accelerometers.

- **Actuators:** In the Internet of Things (IoT), actuators play a crucial role in controlling processes and devices based on data collected from sensors. Actuators are used to execute specific actions based on the analytics and decisions made by the system. For example, in an environmental monitoring system, IoT actuators can adjust water flow or operate ventilation systems based on data received from sensors to maintain specific environmental conditions. This ability to control and direct automated processes in response to collected data enhances system efficiency and enables smart interaction and control of the surrounding environment[31].

- **Communication Gateways:** In the realm of the Internet of Things (IoT), communication gateways serve as essential intermediaries, facilitating the seamless exchange of data between IoT devices and the cloud. These gateways act as bridges, translating and transmitting data from various devices to centralized cloud servers where it can be stored, processed, and analyzed. By leveraging protocols such as MQTT, HTTP, or CoAP, communication gateways ensure reliable and efficient data transfer, even across heterogeneous networks with diverse devices and protocols. This enables real-time monitoring, analysis, and control of IoT systems, empowering businesses and organizations to make informed decisions based on timely insights derived from IoT-generated data[32].

- **Cloud:** In the realm of the Internet of Things (IoT), the cloud serves as a central hub where data is stored and processed, enabling analysis and informed decision-making. IoT systems collect vast amounts of data from various devices, which is then transmitted to the cloud for storage and subsequent processing. This allows for comprehensive data analysis and the application of machine learning and artificial intelligence techniques to extract insights and generate predictions. With the cloud's ability to efficiently process data and provide massive resources, IoT systems can enhance their decision-making capabilities based on accurate data and comprehensive information processed in the cloud.

- **User Interface:** the user interface plays a crucial role in enabling users to interact with the system and monitor its status. This interface serves as a bridge between humans and IoT devices, allowing users to access and control connected devices, as well as receive real-time updates and insights into the system's performance. Whether through web-based dashboards, mobile applications, or voice-activated assistants, the user interface provides intuitive and user-friendly ways for individuals to manage and engage with IoT systems. By facilitating seamless communication and interaction, the user interface enhances the usability and accessibility of IoT technology, empowering users to make informed decisions and effectively manage their connected environments.

- **Functions:** In IoT, functions refer to the operations performed by the system, which include collecting and analyzing data to automatically control the environment. These functions involve processes such as gathering data from sensors, processing it in the cloud, and triggering actions or adjustments based on predefined rules or algorithms. For example, in a smart home system, functions may include monitoring indoor temperature and humidity levels, analyzing energy consumption patterns, and automatically adjusting heating or cooling systems to optimize comfort and efficiency.

  Additionally, IoT systems often incorporate user interaction features that allow individuals to monitor and adjust settings as needed. This can be achieved through various interfaces such as mobile apps, web portals, or voice-controlled assistants, enabling users to access real-time data, receive notifications, and manually override automated processes when necessary. By combining automated functions with user interaction capabilities, IoT systems provide a flexible and responsive environment that adapts to both automated algorithms and user preferences, enhancing convenience, efficiency, and control.

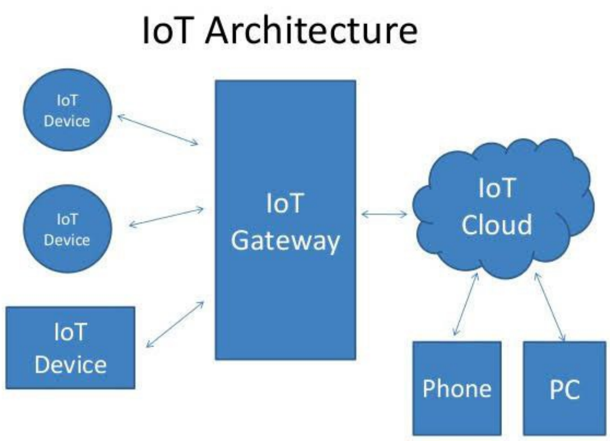

Figure 6: Architecture of IOT.

2.1.7 The Importance of IoT

The Internet of Things (IoT) has revolutionized workplaces by eliminating repetitive tasks and enhancing operational efficiency, enabling people to work in a smarter and more effective manner. For example, IoT devices such as smartphones and smartwatches enable continuous data collection and analysis, empowering businesses to make informed decisions that enhance productivity and improve workflow[33]. IoT is revolutionizing various sectors of work by improving communication and facilitating information exchange, thereby contributing to increased productivity and creativity at all levels. It serves as a driving force for change in the workplace, offering immense potential to improve operational efficiency, enhance collaboration, and develop entirely new business models. The Internet of Things offers significant benefits for individuals and organizations alike, Importance of IoT:

- **Improved Efficiency:**IoT allows for automation of tasks, data collection, and process optimization. This can lead to significant cost savings and improved efficiency across industries.

- **Better Insights:**Sensors and connected devices generate a wealth of data. Businesses can leverage this data for real-time insights, predictive maintenance, and informed decision-making.

- **Increased Automation:**The automation of the Internet of Things (IoT) represents a qualitative leap in the world of technology, enabling devices to perform tasks autonomously without direct human intervention. This smart automation offers companies tremendous capabilities to reduce labor costs, improve decision-making speed, enhance operational efficiency, and develop innovative business models.

  IoT automation involves integrating artificial intelligence and machine learning technologies with IoT devices, enabling them to operate independently and automatically. This automation includes various tasks, such as self-control of systems, data collection and analysis, and automatic task execution.

  IoT automation provides significant benefits for companies, including reducing labor costs, improving decision-making speed, enhancing operational efficiency, and driving innovation. Artificial intelligence and machine learning are among the most important factors driving the development of IoT automation, promising a future full of immense possibilities.

  Overall, IoT automation represents a technological revolution that brings about a significant transformation across various sectors. This smart automation contributes to enhancing the competitive position of companies, improving the quality of products and services, and creating new opportunities for growth and development.[34]

- **Comfort and Well-being:** IoT devices enable remote control of home appliances, security systems, and surveillance, providing comfort and peace of mind. For example, you can perform actions remotely or receive alerts in case of unusual movement.

- **Innovation Revolution Across Various Fields:** The Internet of Things (IoT) serves as a powerful catalyst for innovation across various fields, providing vast capabilities for developing smart solutions that change the way we work and live. Among the most important of these fields are: healthcare, smart cities, industry, agriculture, aquaculture, and others...

2.2 Smart Aquaculture

The intelligent aquaculture system is a modern technology designed to enhance and increase the efficiency of fish and aquatic organism farming through the use of artificial intelligence and the Internet of Things. These systems rely on advanced sensors that monitor various environmental factors such as water quality, temperature, and oxygen levels, providing the necessary data for better management of fish farms. By analyzing this data in real-time, it is possible to improve farming conditions, reduce waste, and increase productivity in a sustainable and efficient manner.

2.2.1 Using IOT in aquaculture

Using IoT (Internet of Things) in aquaculture offers numerous benefits by enabling real-time monitoring, automation, and data-driven decision-making. Here's how IoT can be applied in aquaculture:

- **Water Quality Monitoring:** IoT sensors can continuously monitor water parameters such as temperature, pH levels, dissolved oxygen, turbidity, and salinity. Any deviations from optimal conditions can be detected early, allowing for prompt corrective action.
- **Feeding Optimization:** Smart feeders equipped with IoT sensors can dispense feed based on fish behavior, environmental conditions, and growth rates. This prevents overfeeding, reduces waste, and ensures that fish receive the right amount of nutrition.
- **Environmental Monitoring:** IoT devices can monitor environmental factors such as air temperature, humidity, and light intensity in the aquaculture facility. This information can help optimize conditions for both fish health and the efficiency of the operation.
- **Fish Tracking and Behavior Monitoring:** RFID tags or acoustic tags can be used to track individual fish within the aquaculture system. This data can provide insights into fish behavior, growth patterns, and health status.
- **Remote Monitoring and Control:** Aquaculture facilities can be remotely monitored and controlled through IoT-enabled platforms. This allows farmers to keep track of operations, receive alerts in case of emergencies, and make adjustments from anywhere with an internet connection.
- **Predictive Analytics:** By collecting and analyzing data from various IoT sensors over time, predictive analytics algorithms can forecast trends, identify patterns, and provide recommendations for optimizing aquaculture practices.
- **Energy Management:** IoT devices can help optimize energy usage in aquaculture facilities by monitoring and controlling equipment such as pumps, aerators, and heaters based on demand and efficiency.
- **Health Monitoring:** IoT-enabled cameras and sensors can monitor fish behavior and detect signs of disease or stress early on. This early detection allows for timely intervention to prevent widespread outbreaks and minimize losses.

- **Supply Chain Management:** IoT can be used to track and trace fish from farm to fork, providing transparency and ensuring quality and safety throughout the supply chain.

- **Integration with other technologies:** IoT can be integrated with other emerging technologies such as AI (Artificial Intelligence) and ML (Machine Learning) to further enhance decision-making processes and optimize aquaculture operations.

2.2.2 The Importance of IoT in Aquaculture

Monitoring water quality is considered a fundamental aspect in aquaculture, as the effective success of this process largely depends on the availability of suitable aquatic environments. Fish farmers face numerous challenges in monitoring and improving water quality due to the complexities associated with required standards and indicators. With the advancement of Internet of Things (IoT) technologies, fish farmers can now utilize advanced sensor devices to accurately and efficiently monitor water quality. This technology enables farmers to obtain real-time, precise data about the conditions of aquatic basins, such as temperature, dissolved oxygen levels, and others. Using IoT technology, data collected from sensor devices can be directly transmitted to the cloud, giving farmers the ability to remotely and in real-time monitor water quality. With these technologies, farmers can make quick and accurate decisions to ensure a healthy aquatic environment conducive to fish growth. Furthermore, IoT systems provide large amounts of data that can be accurately analyzed using artificial intelligence, helping to identify trends and patterns in water quality and predict potential problems before they occur. These technologies can offer opportunities to improve the efficiency of aquaculture operations, reduce costs, and increase productivity. The importance of IoT technology in monitoring water quality in aquaculture lies in:

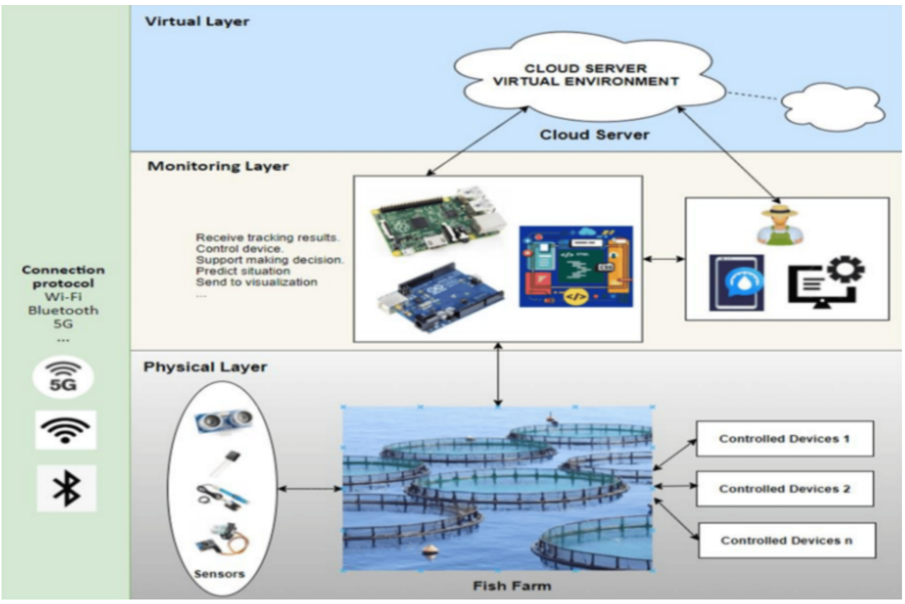

Figure 7: Internet of Things (IoT) Aquaculture System[35]

- Accurately monitoring and controlling the aquaculture environment, tracking factors such as water temperature, oxygen levels, and salinity using sensor devices and transmitting the data to the cloud. This contributes to predicting potential problems such as diseases and sudden environmental changes, allowing farmers to take preventive measures to maintain the safety of their farms.

- Helping improve feeding processes for fish and aquatic animals, leading to proper and rapid growth and development.
- Contributing to improving the efficiency of aquaculture operations, reducing costs, and increasing productivity by utilizing accurate data and making effective decisions based on it. Investment in IoT technology in the aquaculture sector contributes to enhancing national economic growth by increasing production and promoting sustainable development.

2.2.3 Conclusion

In conclusion, the Internet of Things has sparked a true digital revolution in our daily lives, opening up new horizons that we had never imagined before. It has had a significant impact on various aspects of human life, including healthcare, industry, agriculture, and aquaculture, by enabling wide-ranging communication and interaction between devices, thus enhancing automation, efficiency, and innovation.
For instance, in the field of aquaculture, the Internet of Things plays a vital role in monitoring and maintaining water quality, which is essential for the health and growth of aquatic organisms, thereby ensuring an ideal environment for them.
Looking ahead, we anticipate seeing more innovations and applications that will make our lives easier, more comfortable, and more efficient in the future. By harnessing the power of the Internet of Things, we can confront challenges and drive growth in many vital sectors.
In summary, the Internet of Things represents not only a technological revolution but also a path towards enhancing productivity, efficiency, and sustainability in aquaculture and other industries. Through collaboration, innovation, and investment, we can explore the full potential of the Internet of Things and shape a better future for aquaculture and other fields.

The next chapter will focus specifically on the crucial issue of water quality monitoring. This component is essential for ensuring the health and growth of aquatic organisms. We will examine different water quality parameters, such as temperature, pH, and dissolved oxygen levels, and their impact on aquatic ecosystems. Additionally, we will discuss sensor technologies and methodologies for data collection and analysis that enable real-time monitoring. Finally, we will address the challenges associated with implementing these systems and potential solutions to enhance their efficiency and reliability in diverse aquaculture production environments.

Chapter 03

3 Monitoring of Water Quality and Related Works

3.1 Monitoring of water

Accurate monitoring of water quality parameters such as dissolved oxygen (DO), salinity, temperature, and pH levels is essential for ensuring the success of intensive aquaculture.[36] Fluctuations in the physical parameters of water directly affect the health and growth of aquatic organisms.

3.1.1 Traditional Monitoring

Traditional methods of monitoring water quality in aquaculture, such as manual testing and visual inspections, have significant limitations. These approaches are often labor-intensive, require frequent human intervention, and may not provide real-time data necessary for proactive management. Therefore, there is an urgent need to develop automated and continuous monitoring solutions that can provide precise and timely data on critical water quality parameters. This enables effective management and informed decision-making to maximize fish health and productivity in aquaculture[37].
Water quality in intensive aquaculture systems can be likened to the living environment of aquatic organisms. Just as humans need clean air and potable water to stay healthy and active, aquatic organisms require specific water quality parameters to grow and reproduce properly.
Four key parameters play a crucial role in determining water quality: PH, temperature, oxygene,salynity

Figure 9: show the water quality monitoring technology

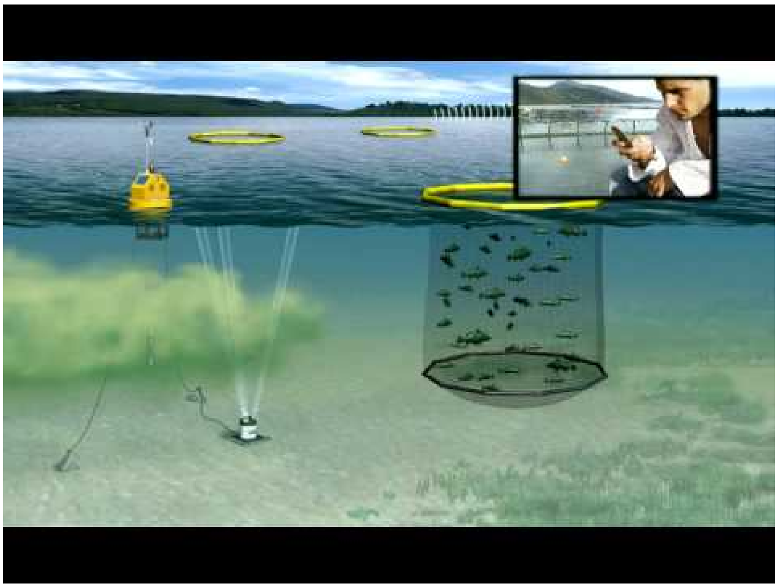

Figure 8: Aquaculture Water Quality Monitoring [38].

3.1.2 Risks of Water Quality Fluctuations:

Fluctuations in water quality parameters can lead to various risks, including:

Oxygen Depletion: May lead to the death of fish and other aquatic organisms.

Changes in Salinity: Can result in fish mortality or disease.

High Temperature: May cause reduced appetite, stunted growth, and increased risk of disease.

Low Temperature: Can lead to decreased activity, weakened immune system, and increased risk of disease.

pH Changes: May result in fish mortality or disease.[39,40]

3.1.3 Monitor water and achieve optimal environments in aquaculture

Water quality monitoring is an essential aspect of various industries, including aquaculture, agriculture, and environmental management. Traditional methods of water quality assessment often involve manual sampling and laboratory analysis, which can be time-consuming, expensive, and labor-intensive. To address these limitations, Internet of Things (IoT) technology has emerged as a powerful tool for real-time, continuous, and cost-effective water quality monitoring[41].

IoT sensors play a central role in water quality monitoring systems. These sensors can be deployed in various water bodies, such as rivers, lakes, oceans, and aquaculture tanks, to collect real-time data on a wide range of water quality parameters. Common IoT sensors for water quality monitoring include:[42]

– Dissolved Oxygen (DO) sensors: Measure the concentration of dissolved oxygen in water, which is crucial for aquatic life.

– pH sensors: Measure the acidity or alkalinity of water, which affects the availability of nutrients and the health of aquatic organisms.

– Temperature sensors: Monitor water temperature, which influences various biological and chemical processes in water.

– Conductivity sensors: Measure the electrical conductivity of water, which is an indicator of dissolved salts and minerals.

– Turbidity sensors: Assess the clarity of water by measuring the amount of suspended particles.[43]

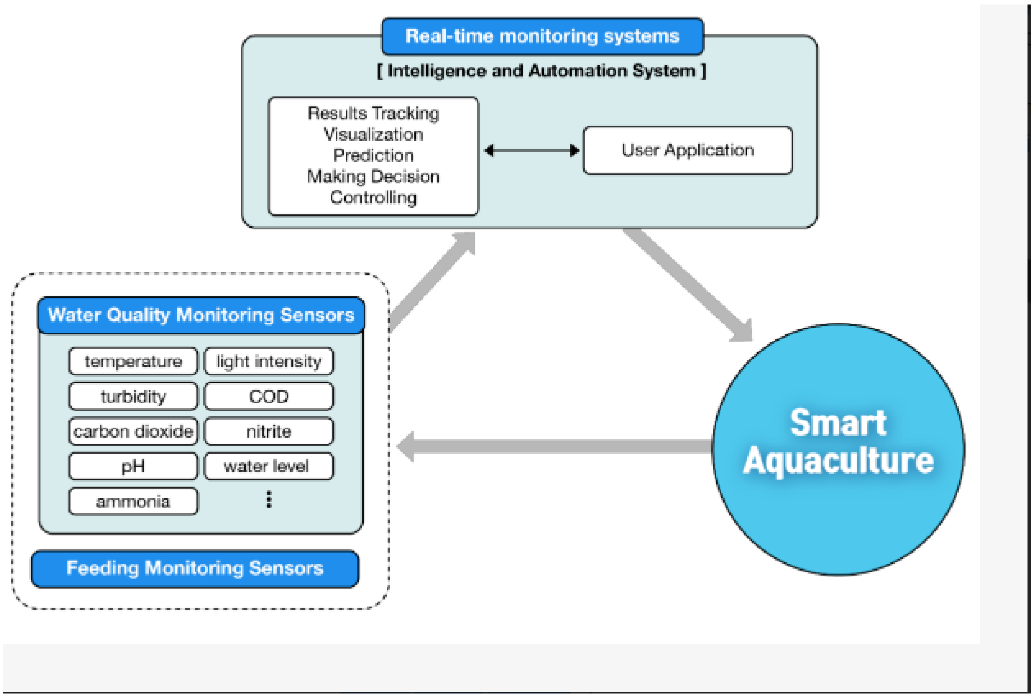

Figure 9: Smart Aquaculture Sensors and Monitoring of Water Systems[44]

IoT Data Collection and Transmission:

IoT sensors collect water quality data at regular intervals and transmit it wirelessly to a central data collection point. This can be achieved using various communication protocols, such as Wi-Fi, Bluetooth, cellular networks, or satellite communication. The choice of communication protocol depends on factors like sensor location, distance from the data collection point, and power availability.[42][21]

Data Processing and Visualization:

The collected water quality data is then processed and analyzed to extract meaningful insights. This may involve data cleaning, filtering, and applying algorithms to identify patterns, trends, and anomalies. The processed data is often visualized using dashboards, charts, and graphs to provide a clear and understandable representation of water quality conditions.[45]

IoT-Enabled Water Quality Management Systems:

IoT-enabled water quality monitoring systems offer several advantages over traditional methods:

– Real-time data: Provide continuous monitoring of water quality parameters, enabling immediate detection of water quality issues.

– Remote access: Allow users to access and view water quality data from anywhere, anytime, using web browsers or mobile applications.

– Automated alerts: Trigger alerts when water quality parameters exceed predefined thresholds, prompting timely interventions.

– Historical data analysis: Enable historical data analysis to identify trends, assess water quality changes over time, and predict potential issues.

IoT-based water quality monitoring systems are finding applications in various sectors, including:

– Aquaculture: Monitor water quality in fish farms to optimize fish health, growth, and productivity.

– Environmental monitoring: Track water quality in rivers, lakes, and oceans to assess pollution levels and protect aquatic ecosystems.

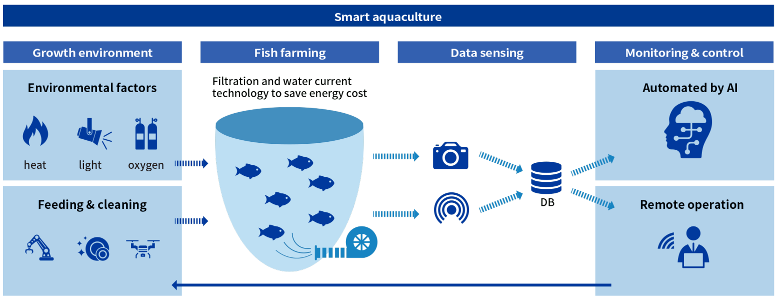

Figure 10: IoT Monitoring water quality system block diagram[46]

3.1.4 Challenges in Monitoring Water Quality in Aquaculture

Monitoring water quality in aquaculture presents significant challenges due to the crucial importance of parameters such as temperature, pH, turbidity, and dissolved oxygen levels. These parameters play a vital role in fish health and productivity, directly influencing their well-being and growth. Variations in these factors can disrupt the delicate balance of the aquatic environment, affecting the fish's ability to develop optimally and maintain stable productivity[47].

Critical Parameters of Water Quality

In aquaculture, critical parameters of water quality include temperature, pH, turbidity, and dissolved oxygen levels. Temperature affects fish metabolic processes, while inadequate pH levels can compromise their immune system and growth. Increased turbidity reduces light penetration, impacting photosynthesis in aquatic plants and fish visibility. Insufficient dissolved oxygen levels can lead to respiratory distress and even fish mortality[48].

Impact on Fish Health and Productivity

Fish health and productivity in aquaculture are directly impacted by water quality. Temperature fluctuations can stress fish and compromise their immune systems, making them more susceptible to diseases. Imbalanced pH can disrupt fish physiology, while increased turbidity can reduce feeding efficiency and increase predation risk. Insufficient dissolved oxygen levels reduce fish respiratory efficiency, resulting in slowed growth and overall productivity decline in aquaculture operations[49].

3.2 Related works

In this section, we will present a review of related works in the field of water quality monitoring for aquaculture. Recent advancements have demonstrated the potential of IoT and related technologies to revolutionize aquaculture practices.

Yang et al. (2012): This study emphasizes the importance of water quality information collection in industrial aquaculture. The researchers utilized wireless sink nodes to gather water quality data, achieving an accuracy of 90.7%.. This method is energy-efficient as it eliminates redundant information, thereby reducing data transmission requirements. The deployment of sink nodes proved to be a significant advancement in aquaculture data collection, facilitating better decision-making processes.

Simbeye amp; Yang (2014): In this research, a network of wireless sensors combined with single-chip computer technology was deployed for intensive aquaculture monitoring. The system not only tracked environmental variables but also provided notifications via SMS when parameters deviated from normal ranges. After six months of testing, the system achieved a reasonable degree of accuracy and proved effective in maintaining stability under varying conditions. This approach demonstrated the practical application of IoT technologies in maintaining optimal aquaculture environments.

Liu et al. (2016): This study introduced a comprehensive wireless network system designed for real-time monitoring of aquaculture environments. The system included sensor nodes, base stations, a central controller, and support for web and mobile users. It effectively enhanced the fish breeding atmosphere, increased production income, and reduced labor intensity by automating environment and waste discharge management. Field tests showed a 98 accuracy rate, highlighting the system's reliability and effectiveness.

Parra et al. (2018): The researchers developed a series of sensors to monitor fish activity and water quality in rearing tanks. Their system monitored various factors such as water quality, tank conditions, feed distribution, and fish behavior. A smart algorithm minimized energy waste during data transmission. The system used a wireless sensor network (WSN) with three nodes, which communicated data over a local area network (LAN) to an internet database. The algorithm also identified inappropriate values and issued alerts. This system demonstrated the integration of smart technologies to enhance energy efficiency and data accuracy in aquaculture monitoring.

Ismail et al. (2020): Addressing the challenges in fishpond management, this research introduced a real-time identification and monitoring system based on IoT technology. Ismail and colleagues used a qualitative approach to understand the perspectives and ideas of fishpond farmers. The proposed model continuously assessed and tracked water quality, ensuring optimal conditions for aquaculture organism growth and survival. The system enabled prompt preventive measures, reducing losses and boosting efficiency. This study highlighted the potential of IoT to transform aquaculture practices, especially in developing regions.
Fearghal O'Donncha and Jon Grant (2020)
Precision Aquaculture This research reviews innovative solutions for aquaculture challenges through IoT

and cloud computing technologies. It focuses on precise water quality monitoring using interconnected sensing technologies and edge computing for efficient data analysis. The study also explores federated learning for local training of machine learning models while preserving data privacy. A practical case study in Eastern Canada demonstrates data-driven insights for sustainable aquaculture intensification.

Author (2019) Towards Precision Aquaculture: A High Performance, Cost-effective IoT Approach** This research provides an overview of precision aquaculture, focusing on IoT technologies to enhance farming operations with precision and cost-effectiveness. It explores how interconnected sensing technologies monitor, analyze, and interpret data to support decision-making. A case study in Eastern Canada showcases the collaboration of industry, technology, and academic partners to promote sustainable aquaculture intensification. The study also discusses challenges such as connectivity and standardization.

Liu et al. (2016) Water Quality Monitoring and Control for Aquaculture Based on Wireless Sensor Networks This research presents a wireless sensor network system for monitoring and controlling water quality in aquaculture. The system uses wireless sensor nodes to collect real-time data on various water parameters, which are transmitted to a central computer via ZigBee communication. The data is analyzed using LabVIEW software, with notifications sent to farm owners via a GSM module. Experimental evaluations demonstrate the system39;s feasibility for real-world applications in optimizing aquaculture environments.

3.3 Limitations

While previous works on IoT-based monitoring and control systems for aquaculture, such as those by Yang et al. (2012), O'Donncha and Grant (2020), and Liu et al. (2016), have made significant contributions in terms of implementing smart sensors and real-time monitoring, fail to effectively integrate environmental sensor data with management systems. This lack of comprehensive integration hinders operators from obtaining real-time insights into critical parameters such as water quality, fish health, and system performance. This gap compromises the ability to make informed and timely decisions necessary to maintain aquatic stock health and enhance overall profitability. .

Our proposed solution addresses this gap by integrating an extensive database that collects and stores crucial data from various sensors, as well as detailed tables on health, nutrition, incidents, and medication. This database not only provides immediate benefits to farmers by offering actionable insights and enhancing farm management but also lays the groundwork for future applications of machine learning and advanced analytics. Furthermore, the use of a sensor and actuator simulator in our system design allows for testing and optimization in a controlled environment, ensuring robustness and efficiency before deployment in real-world scenarios. This holistic approach not only improves current aquaculture practices but also sets the stage for continued innovation and sustainability in the sector.

3.4 Conclusion

In conclusion, the development and implementation of IoT-based monitoring and control systems in aquaculture represent a pivotal advancement in the field, offering numerous benefits and paving the way for future innovations. This chapter has highlighted several key studies and their contributions, underscoring the importance of real-time monitoring in enhancing productivity, sustainability, and operational efficiency within aquaculture operations.

The reviewed studies have demonstrated how IoT technologies, such as smart sensors, wireless networks, and data analytics platforms, can effectively monitor and manage critical parameters like water quality, environmental conditions, and fish health in aquaculture settings. These technologies enable farmers to make data-driven decisions, promptly detect deviations from optimal conditions, and implement corrective measures, thereby minimizing risks and improving overall farm management.

However, despite the significant progress made, there are notable limitations in existing research. Many studies have focused primarily on technical aspects and immediate benefits of real-time monitoring without fully integrating data across different domains, such as health records, nutrition, incidents, and medication. This fragmentation hinders the holistic understanding and management of aquaculture ecosystems. Our proposed solution addresses these gaps by introducing a comprehensive database that integrates diverse datasets crucial for effective farm management. This integrated approach not only consolidates information but also facilitates advanced analytics and machine learning applications. By leveraging this unified data platform, farmers can gain deeper insights into their operations, predict trends, optimize resource allocation, and enhance sustainability practices. Furthermore, the incorporation of a sensor and actuator simulator has proven invaluable in testing and refining system functionalities before deployment, ensuring robustness and reliability in real- world applications. This simulation capability minimizes risks associated with technological integration and operational disruptions, providing a controlled environment to validate system performance and optimize configurations.

Chapter 04

4 System Design and Implementation

4.1 System Design

In designing our IoT-based water quality management system for aquaculture, we meticulously addressed several key objectives. First, we focused on developing a comprehensive IoT sensor network capable of accurately measuring and monitoring critical water quality parameters such as temperature, pH, and oxygen levels. This data is transmitted to a cloud database, forming the backbone of our system and implemented actionable insights and enabling automated control through connected actuators. Additionally, we integrated a comprehensive farm management system to track essential information on feed, medication, and incidents, facilitating informed decision-making and operational efficiency. To ensure a seamless transition from design to physical deployment, we employed the Wokwi simulator. This virtual environment allowed us to simulate and validate the functionality of sensors and actuators, enabling rapid iteration and debugging while reducing hardware costs and minimizing risks associated with real-world testing.

4.1.1 Proposed Architecture

AQUALINK is a smart system that utilizes advanced technologies such as Internet of Things (IoT), data analytics, and automation to enhance the efficiency and sustainability of aquaculture practices. The aim of a smart aquaculture system is to monitor and analyze various environmental parameters and automatically respond to them to ensure optimal conditions for the growth and health of aquatic organisms. This smart aquaculture system includes:

A variety of sensors installed in the simulated aquatic environment to monitor parameters such as temperature, oxygen levels, salinity, pH, etc.

A system for transmitting sensor data to a central analysis platform via the internet.

The ability to take automatic actions or send alerts to operators based on the analysis .

User-friendly interfaces for monitoring and controlling the system, receiving alerts, and accessing reports.

These technologies and tools, a smart aquaculture system can improve production efficiency, reduce operational costs, and provide an optimal environment for the growth and development of aquatic organisms, contributing to the sustainability of aquaculture.

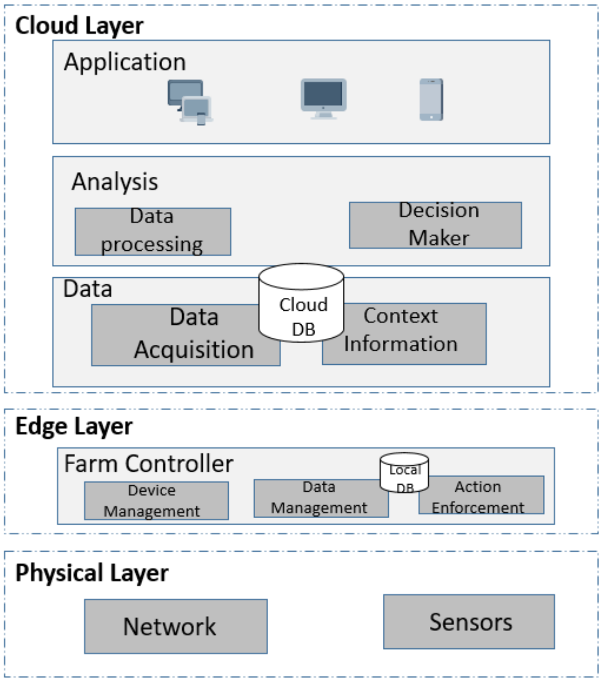

Figure 11: IOT Layer Architecture

Physical Layer:

In aquaculture projects, the physical layer comprising networks and sensors is crucial for real-time monitoring and environmental control. This layer ensures efficient operations and informed decision-making by providing continuous data on environmental parameters such as pH levels, temperature, dissolved oxygen, salinity, and ammonia/nitrite/nitrate levels. It also includes wireless and wired network infrastructure, data collection and transmission systems, control systems like automated feeders and aeration systems, and environmental sensors such as weather stations and light sensors. These components integrate with IoT platforms for data analytics, provide regular maintenance, and ensure user-friendly interfaces, enhancing automation, disease prevention, and regulatory compliance.

Edge Layer:

The edge layer is essential for device management, data management, and action enforcement, processing data near its source to enhance real-time monitoring and control. Device management includes configuration, monitoring, diagnostics, firmware updates, security, and lifecycle management. Data management involves data collection, aggregation, preprocessing, edge analytics, and local storage. Action enforcement comprises rule-based decision-making, real-time control, event notifications, and integration with control systems, providing immediate response, reducing data latency, optimizing bandwidth, improving reliability, and enabling scalability.

Cloud Layer:

The cloud layer is fundamental for supporting decision-making through data analysis capabilities, data processing, acquisition, and contextual understanding to optimize aquaculture operations. This layer involves data aggregation from multiple sources, data transformation through normalization and feature engineering, and real-time processing for immediate actions and trend analysis. Real-time sensor data collection, data logging, and integration with external data such as weather and market information via APIs and webhooks are performed. Contextual environmental and operational information provides a comprehensive understanding, enhancing immediate responses and future needs predictions. The cloud layer improves the efficiency and sustainability of aquaculture operations through comprehensive data management and actionable insights.

The database plays a crucial role within the Cloud Layer of the IoT architecture, serving as a central hub for data aggregation, storage, and analysis in smart aquaculture systems. It functions as a repository where data collected from various sensors, such as pH, temperature, dissolved oxygen, and turbidity sensors, are aggregated in real-time. This aggregated data is then securely stored, ensuring reliability and accessibility for future analysis and decision-making processes. Moreover, the database facilitates advanced analytics, including trend analysis, predictive modeling, and anomaly detection, which are essential for optimizing aquaculture operations. By leveraging the database within the Cloud Layer, stakeholders can gain valuable insights into environmental conditions, optimize resource management, and enhance overall operational efficiency in smart aquaculture.

4.1.2 Aquaculture manegement system design

The design of the Aquaculture Management System is a comprehensive framework aimed at integrating IoT technologies with advanced management practices to enhance the efficiency and productivity of aquaculture operations.

The database design for the aquaculture management system is a pivotal element that ensures the systematic storage, retrieval, and management of critical data related to water quality, fish health, feeding schedules, and incident reports. Our database comprises several interconnected tables

4.1.3 MySQL Database Design

A database is an organized collection of data that can be easily accessed, managed, and updated. In a smart aquaculture system, the database serves as the backbone of the system, storing all vital information related to the system and providing it when needed.

The database includes the following types of data:

First, user (registrant) data, including full names, email addresses, phone numbers, addresses, and account details such as usernames and passwords. Second, aquaculture tank data, which includes the type of tanks, their sizes, types of fish or other marine creatures present, water levels, temperatures, oxygen levels, nitrate levels, and other vital indicators.

Third, sensor data, which includes readings from various sensors (such as temperature, oxygen levels, nitrate levels), the date and time of each reading, and warnings or alerts based on sensor readings. Fourth, feeding data, which includes types of food used, feeding schedules, and quantities of food provided. Finally, health and treatment data, which includes records of diseases, treatments provided, and medications used.

Benefits of Storing Registrant Information Storing registrant information offers several critical benefits for the smart aquaculture system. One such benefit is service personalization, where personalized recommendations can be provided to users based on their data and interaction history with the system. This enables users to have a tailored experience that increases operational efficiency and meets their needs more effectively.

Another benefit is security management, as storing account information facilitates access control to the system, enhancing security and protecting sensitive data. Additionally, storing registrant information enables effective communication with users via email or phone to notify them of important updates or alerts.

By implementing these practices, the smart aquaculture system can maximize the use of available data and continuously improve its operations.

Database Structure: The structure of our database,is composed of tables and their relationships.

o Tables for water quality parameters (pH, temperature, dissolved oxygen, etc.).

o Tables for operational data (feed and medication purchases, system configurations)

we describe the main tables and their fields.

User Table

User id (Primary Key): Unique identifier for each user.

User email : email for each

user password : password for each user.

Tank Table

Tank id (Primary Key): Unique identifier for each tank.

size: The size of the tank.

Fish Table

fish id (Primary Key): Unique identifier for each fish.

species: The species of the fish. quantity: The number of fish.

health status: Current health status of the fish.

pond id (Foreign Key): References the pond in which the fish are located.

Feed Table

feed id (Primary Key): Unique identifier for each feed type.

type: Type of feed.

quantity: Amount of feed available.

nutritional content: Nutritional information of the feed.

Medication Table

medication id (Primary Key): Unique identifier for each medication type.

name: Name of the medication.

dosage: Recommended dosage.

usage: Description of how and when to use the medication.

Incidents Table

incident id (Primary Key): Unique identifier for each incident.
description: Detailed description of the incident.
date: Date of the incident. impact: Impact of the incident on the fish and ponds.
response: Actions taken in response to the incident.

4.2 Process of AQUALINK

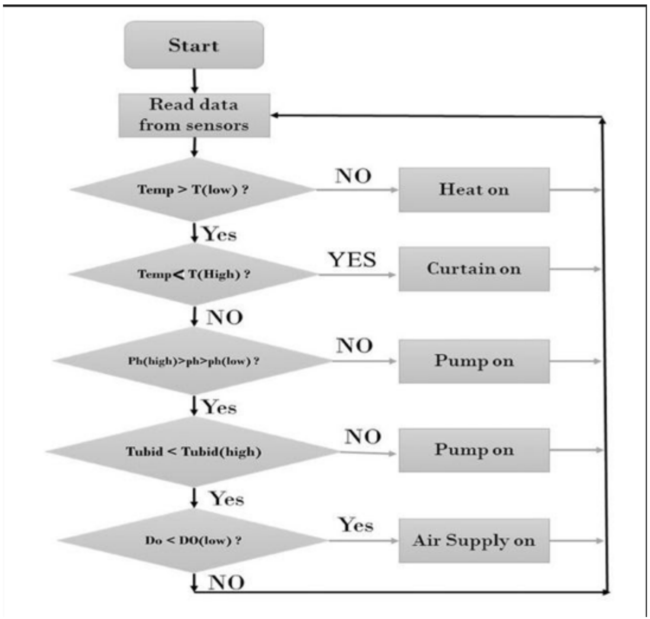

Figure 12: The Process of AQUALINK

The sensors gather data about their respective parameters and transfer it to the cloud server via the Wi-Fi communication protocol for further analysis. extract features and assess their impact on system productivity. A mobile application has been developed to remotely monitor and control the system.
To prevent the effect of heat convection caused by cold wind, a wind protection device powered by an engine is installed. When the water temperature detected by the thermal sensor falls below the target temperature, the vent protection mechanism activates, and the heating system turns on, in accordance with water quality standards to achieve intelligent feeding.
The agitator placed in the pond activates when the oxygen dissipation value measured by the DO cap is less than the desired value. Additionally, the water pump activates if the pH or turbidity readings surpass the predetermined threshold.

When the water temperature falls below the threshold: the heating system turns on, and the vent protection device opens.
When the dissolved oxygen level is below the threshold: the agitator activates. When the turbidity or pH exceed the threshold: the water pump turns on.
So, continuous monitoring of water quality parameters and Automatic adjustment of environmental conditions to maintain optimal is acheived by this process

4.3 The components of Aqualink

the architecture of the intelligent aquaculture system and its operation, in collaboration with IoT .

Sensors and Actuators

Sensors: temperature, pH, dissolved oxygen sensors

Actuators: engine, pump ,regulating water

Connectivity

Network: to connect to the internet. This includes technologies such as Wi-Fi

Communication Protocols: Protocols used to transmit data

Data Management Platform

Data Collection: Methods for aggregating data from sensors.

Data Processing: Analysis and interpretation of collected data, often performed on a cloud platform.

Data Storage

Database: my sql database.

Backend Application (Server)

API: Interfaces for receiving data from sensors and providing services to frontend applications.

Processing: Software that manages data, analyzes it, and makes automated decisions or provides recommendations.

Frontend Application (Dashboard)

User Interface: Dashboard that allows users to visualize and interact with real-time data.

Alerts and Notifications: Systems for alerting users of any anomalies or necessary actions."

4.4 Implementation

We present in this part two categories—hardware implementation and software implementation.

During the implementation phase, Wokwi played a crucial role in validating and refining our IoT-based water quality management system. By simulating sensors and actuators in a virtual environment, we ensured that all components operated as expected and communicated seamlessly within the system. This approach facilitated comprehensive testing of data transmission, sensor accuracy, and system responsiveness without the constraints of physical deployment. Wokwi's simulation capabilities enabled us to detect and address potential issues early, thereby enhancing the reliability and efficiency of our implementation. This rigorous testing framework contributed to the successful integration of our IoT solution into aquaculture environments, meeting performance standards and ensuring optimal operation.

4.5 Hardware Implementation

We have simultaed the following system with wokwi,

Sensors are immersed in water to continuously and accurately monitor the aquatic environment. These sensors include several types, each performing a specific function: the temperature sensor measures the water temperature, the pH sensor measures the acidity level, the salinity sensor measures the salinity level, and the dissolved oxygen sensor measures the amount of dissolved oxygen in the water. Once these sensors are submerged, they begin to collect environmental data immediately, allowing users to monitor and respond to changes in water quality. This process provides vital information about the condition of the aquatic environment, helping to maintain the health of aquatic ecosystems and support the organisms living within them.

4.5.1 Introduction to Wokwi simulation

The Wokwi application offers a solution by enabling online simulation of embedded programming and IoT, providing a safe, cost-effective, and accessible learning tool.The subject of IoT and embedded programming is being taught at the University of Information Technology and Information Security. However, students in Information Technology fields such as Software Engineering, Information Systems, Computer Science, Computer Engineering, and Information Security lack comprehensive knowledge of hardware and related programming. This gap makes it challenging to design, program, and test hardware like Arduino, AT-Mega, and IoT modules. Practical hardware testing can lead to risks of fire and damage, and purchasing individual hardware components can be expensive for students.

4.5.2 Advantagous of Using Wokwi for Simulation of Sensors and Actuators

Wokwi presents the following adventagous
Cost-Effective Learning: Wokwi eliminates the need for students to purchase expensive sensors and actuators, making learning more affordable.
Safety: Students can safely experiment with various sensor and actuator configurations without the risk of damaging physical hardware.
Accessibility: Wokwi is accessible online, allowing students to simulate sensors and actuators from any location with an internet connection.
Instant Feedback: The simulation provides real-time feedback, enabling students to quickly understand the behavior of sensors and actuators in different scenarios.
No Hardware Limitations: Students can simulate an unlimited number of sensors and actuators, which is not feasible with physical hardware due to cost and availability constraints.
Ease of Use: The user-friendly interface of Wokwi makes it easy for students to set up and modify sensor and actuator simulations without extensive technical knowledge.
Rapid Prototyping: Students can rapidly prototype and test their ideas, making it easier to iterate and improve their designs. **Collaboration:** Wokwi allows students to share their simulation projects with peers and instructors, facilitating collaborative learning and feedback.
Community Support: Students can access a wealth of community-contributed projects and examples, helping them learn from others and find inspiration for their own projects.
Advanced Features: Wokwi includes advanced debugging tools and virtual logic analyzers, enabling students to analyze digital signals and debug complex sensor and actuator interactions.
Scalability: The platform can simulate complex systems with multiple sensors and actuators, allowing students to work on large-scale projects.

Environmental Impact: By reducing the need for physical hardware, Wokwi contributes to sustainability and reduces electronic waste.

Consistency: Simulations provide a consistent learning environment, free from the variability and defects of physical components.

Time Efficiency: Students save time on setup and configuration, allowing them to focus more on learning and experimentation.

Error Reduction: Virtual simulations help students avoid common wiring and connection errors that can occur with physical components.

Resource Availability: Wokwi ensures that all necessary components are always available, without the need for students to search for or wait for parts.

***Educational Integration**: The tool can be easily integrated into coursework and assignments, enhancing the curriculum with practical simulation exercises.

Skill Development: Using Wokwi helps students develop important skills in embedded programming and system design, preparing them for real-world applications.

4.5.3 Importance of Simulation in IoT Projects

Cost Efficiency: Reduces the need to purchase expensive hardware components for testing and development.

Risk Mitigation: Prevents potential damage to physical components, ensuring a safe testing environment.

Accessibility: Enables students and developers to work on projects from anywhere, facilitating remote learning and collaboration.

Scalability: Allows testing of complex IoT systems without the constraints of physical hardware availability.

Time Savings: Speeds up the development process by providing immediate feedback and eliminating setup time.

Enhanced Learning: Offers a practical, hands-on learning experience without the need for physical hardware, making it ideal for educational purposes.

Sustainability: Reduces electronic waste by minimizing the need for disposable hardware components.

Collaboration: Facilitates sharing and collaborative development through community projects and feedback.

Consistency: Provides a controlled environment that ensures consistent testing conditions, free from the variability of physical components.

Skill Development: Helps users develop and refine their skills in embedded programming and IoT system design, preparing them for real-world applications.

4.5.4 Programming with Wokwi

To utilize Wokwi, students need to create a free account or log in via Gmail, Facebook, or GitHub. They can then access sample projects or create new ones, enhancing their learning experience through hands-on practice. The platform's accessibility enables students to work on projects anytime, anywhere, without the need for expensive hardware.

4.5.5 Selection of Sensors and Actuators for Simulation

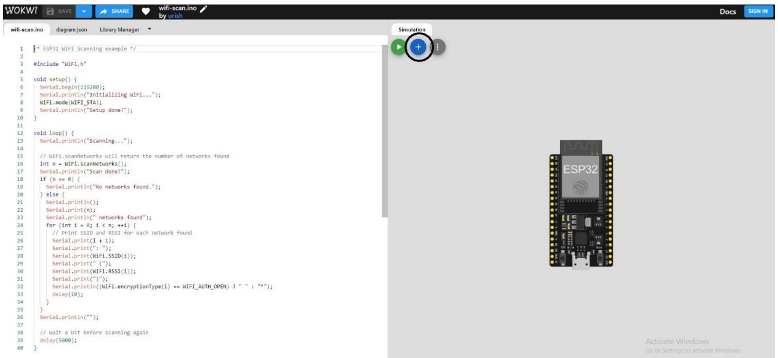

Figure 13: ESP32

The ESP32 is a powerful, low-cost microcontroller with integrated Wi-Fi and Bluetooth capabilities, developed by Espressif Systems. It features a dual-core processor, high performance, and a variety of peripherals, making it suitable for a wide range of applications such as IoT (Internet of Things), wearable electronics, and smart home devices. The ESP32 supports various programming environments, including Arduino, MicroPython, and Espressif's own ESP-IDF, providing flexibility for developers. Its popularity stems from its robust connectivity options, low power consumption, and extensive community support.

Wokwi is an online platform for simulating electronics projects, especially useful for working with microcontrollers like the ESP32, Arduino, and others. The platform allows users to design circuits, write code, and run simulations all within a web browser. To add electronic items in Wokwi, follow these steps:
Open Wokwi: Navigate to the Wokwi website and create a new project or open an existing one.
Access the Components Menu: On the left side of the Wokwi interface, there is a menu with various electronic components and modules.
Search and Select Components: Use the search bar or browse through the categories to find the components you need, such as microcontrollers, sensors, displays, LEDs, and more.
Drag and Drop: Click on a component to select it, then drag it onto the workspace. You can place multiple components and arrange them as needed.
Connect Components: Use the wiring tool to connect components by drawing virtual wires between pins. This step replicates how you would connect components in a physical circuit.
Configure Components: Click on a component to access its properties and configuration options. This might include setting pin numbers, addresses for I2C devices, or initial states for digital components.
Code and Simulate: Once your components are placed and connected, you can write code for your microcontroller in the integrated code editor. Click the "Play" button to run the simulation and see how your circuit behaves.
Wokwi provides a convenient and interactive way to prototype and test electronic circuits without needing physical components, making it an excellent tool for learning and development.

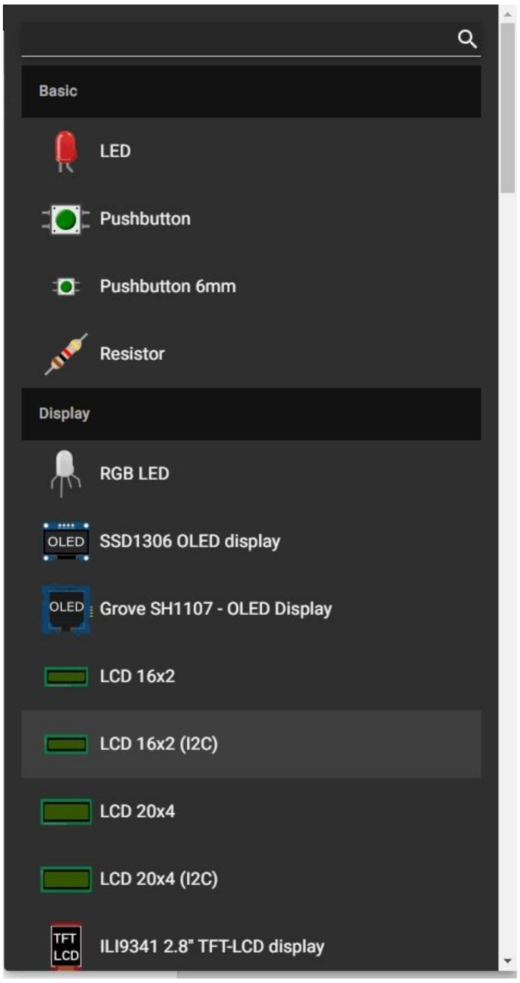

Figure 14: Component List in Visual Programming Application

4.5.6 Creating the Simulation Project in Wokwi

We present steps to create our project in wokwi

Step 1: Access Wokwi

we Open our browser: Wokwi is a web-based tool

Step 2: Sign Up or Log In

We create an account: If we don't have a Wokwi account, sign up using email, or log in with our Google, Facebook, or GitHub account.

Step 3: We Start a New Project with clicking on "New Project" or the plus (+) icon to start a new project.

and after we choose a template

Step 4: We Set Up our Project

With adding components: with using the drag-and-drop interface to add boards, sensors, actuators, and other components to our workspace. we can find these components in the component library.Then we proceed to Connect choosed components

Step 5: We Write our Code

Step 6: We Simulate our Project

by Runing the simulation: we Click the "Play" button to start the simulation. The simulator will compile and run our code, showing the behavior of our virtual components.

Implementing Wokwi in the curriculum allows students to undertake embedded programming and IoT projects conveniently and cost-effectively. Learning from community examples can ignite students' passion and facilitate in-depth understanding of hardware concepts. This is particularly beneficial for Information Technology and Information Security students, who often lack extensive hardware knowledge. With Wokwi, students can practice and experiment without the constraints of funding or hardware availability.

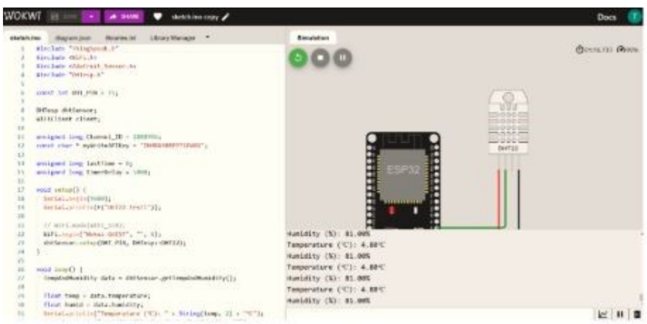

Figure 15: ESP32 WiFi Scanning Code in Simulation Environment

Hardware Components

In the implementation phase of the aquaculture management system, a simulator was developed to emulate sensor data and environmental conditions. This simulator served as a crucial tool for testing the system's functionality and performance under various scenarios without relying solely on real-time data acquisition. By simulating different aquaculture conditions, the system's robustness and responsiveness were thoroughly evaluated before deployment in actual aquafarm settings. This approach not only ensured the system's reliability but also facilitated the identification and resolution of potential issues early in the development process.

We expose in this part the hardware implementation , that we need after the step of simulation of the system. We presents the different compnents of the system that , includes an Arduino Uno along with a set of sensors, which comprise a temperature sensor, a pH sensor, a salinity sensor, and a dissolved oxygen meter... It also contains the board and a USB cable, as well as connecting wires.
These sensors were used to monitor the water quality of aquatic environments. After assembling and calibrating the sensors, they were placed in the relevant aquatic environment, where multiple environmental parameters were continuously measured and monitored. The temperature sensor was used to measure the water temperature, while the pH sensor was used to measure the acidity level. Additionally, the salinity sensor was utilized to measure the salinity level in the water, and the dissolved oxygen meter was used to measure the dissolved oxygen level. By using these sensors, we were able to continuously monitor water quality and provide accurate analysis of the environmental conditions for aquatic organisms. Figure 14 shows diagram of the designed system and the connections of sensors that we have used in this system.

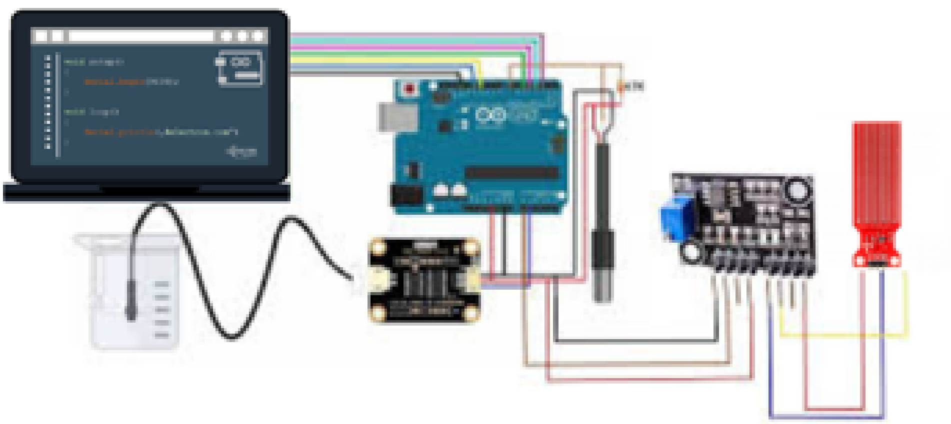

Figure 16: diagram illustrating connections of used sensors.

5.2.1 Arduino Uno

Arduino is an open-source electronics prototyping platform that relies on easy-to-use hardware and software, allowing users to transform analog inputs into specific desired outputs using a simplified version of

C++. The Arduino Uno is one of the most popular boards within this platform, known for being the first small control board featuring USB connectivity to a computer. Programming the board is done using the Arduino Integrated Development Environment (IDE), a free software that can be downloaded from the internet. When the Arduino Uno board is connected to a computer's USB port, installation windows automatically begin installing the necessary drivers to enable communication between the computer and the board.

The Arduino Uno board consists of several key components, including 6 analog input pins for measuring variable signals and 14 digital input/output pins, with 6 of them capable of providing PWM outputs for variable control signals. The board also includes a 16 MHz crystal oscillator to ensure precise timing, an ICSP header for programming integrated circuits, and a reset button for quickly rebooting the board. Additionally, the board supports multiple communication protocols such as UART for serial communication, SPI for high-speed communication, and I2C for communicating with multiple devices using fewer pins.

Thanks to its innovative design and ease of use, the Arduino Uno is employed in a wide range of applications, from educational projects and simple scientific experiments to complex projects in fields like robotics, home automation systems, and prototype development of electronic devices. The extensive community support and ready-to-use libraries make it easy to connect various sensors and electronic components to the board and program them to achieve desired objectives. This comprehensive support makes the Arduino Uno an ideal choice for both beginners and professionals looking to explore the world of electronics and software development[50].

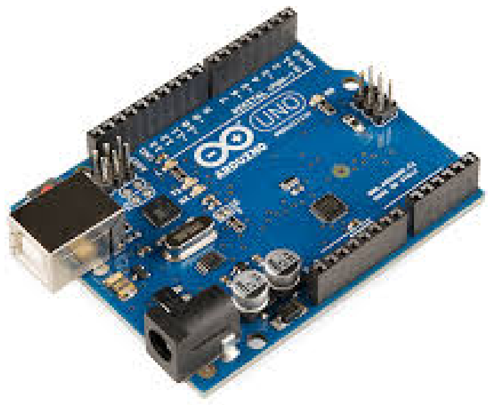

Figure 17: Arduino Uno device

5.2.2 Arduino wifi module ESP32:

The ESP32 is a robust and versatile microcontroller featuring integrated Wi-Fi and dual-mode Bluetooth, produced by Espressif Systems, and widely used in IoT applications due to its low cost, low power consumption, and extensive features. It includes a dual-core Xtensa LX6 microprocessor running up to 240 MHz, numerous GPIO pins, ADCs, DACs, PWM channels, and support for various communication protocols such as SPI, I2C, UART, and CAN. The ESP32 is particularly well-suited for aquaculture projects that require real-time monitoring and control. It can connect various sensors like DS18B20 for temperature, analog pH sensors, DO sensors, and conductivity sensors for salinity measurement. With its Wi-Fi capabilities, the ESP32 can connect to local networks, host web servers, and send data to IoT platforms such as AWS IoT, Google Cloud IoT, or ThingSpeak for advanced analytics and visualization. It can also control aquaculture systems, including automated feeders, aeration systems, and water pumps based on sensor readings. The ESP32 is programmable via Arduino IDE, ESP-IDF, or MicroPython, making it accessible for both beginners and advanced users[51].

Figure 18: Arduino wifi module ESP32

5.2.3 Sensors:

Sensors are electronic devices used to detect changes in the surrounding environment and convert these changes into measurable or analyzable signals. They play a crucial role in many industrial, commercial, and consumer applications, and are fundamental components in modern systems such as automation, robotics, smart devices, medical systems, and more.Here are some sensors and their characteristics[52]:

Temperature Sensor:

The waterproof temperature sensor is ideal for measuring the temperature of liquids or substances in wet conditions. This sensor operates within a temperature range of -55°C to +125°C and can be powered by an electric current ranging from 3.0 to 5.5 volts. However, due to the PVC-coated cable, it is recommended to keep the temperature below 100°C to avoid damage. The sensor uses the 1-Wire communication protocol, allowing multiple sensors to be connected on the same data line, making it versatile. To connect the sensor with an Arduino, the DallasTemperature.h library is required. This library provides easy-to-use commands for reading temperature data from the sensor, simplifying the integration process and ensuring accurate temperature measurements[53].

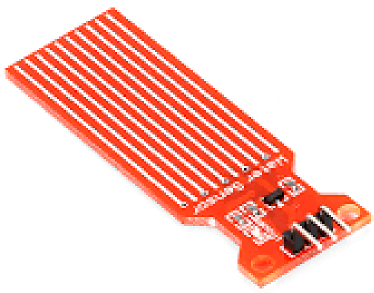

Figure 19: Temperature sensors

voltage	3 - 5 V
Measuring range	-55 $_{+}125C$
Accuracy	±0.5°C
Conversion time	750ms at 12-bit.

Table 1: Specifications of Temperature Sensor[54]

pH Sensor:

The pH sensor is ideal for measuring the acidity of various liquids, making it suitable for scientific, industrial, and agricultural applications. The sensor operates within a pH range of 0 to 14 and features high reading accuracy. It can be powered by a current ranging from 3.3 to 5.5 volts. The sensor requires regular calibration to ensure optimal accuracy and can be calibrated using standard pH calibration solutions. To connect the sensor with Arduino, the "DFRobot$_{P}H.h$”

library is used, providing easy-to-use commands for reading pH data from the sensor, simplifying the integration process and ensuring accurate pH measurements[55].

Figure 20: PH Sensor

voltage	5 V
Measuring range	0 - 14 pH.
Operating temperature	0 - 60 ℃.
Accuracy	0.1 pH (25 ℃).
Response time	less than 1 min

Table 2: Specifications of pH Sensor[56]

Salinity Sensor:

The water salinity sensor is ideal for measuring the concentration of dissolved salts in liquids, crucial for monitoring water quality in environmental, agricultural, and industrial applications. The sensor typically operates within a salinity range of 0 to 50 parts per thousand (ppt) and features reading accuracy up to ±1 . It can be powered by a current ranging from 3.0 to 5.0 volts. To connect the sensor with Arduino, the DFRobot$_EC.h$

library is used, providing easy-to-use commands for reading salinity data from the sensor, simplifying the integration process and ensuring accurate salinity measurements

Figure 21: salinity Sensor

Input voltage	3.3 - 5 V
Output voltage	0 - 2.3 V.
Measuring range	0 - 1000 ppm.
Operating temperature	0 - 55 ℃.
Accuracy	± 10 F.S. (25 ℃).
Response time	less than 1 min.

Table 3: Specifications of Salinity Sensor[57]

Dissolved Oxygen Sensor:

The dissolved oxygen sensor is ideal for measuring the concentration of dissolved oxygen in liquids, essential for monitoring water quality in environmental, agricultural, and industrial applications. The sensor operates within a concentration range of 0 to 20 mg/L and features reading accuracy up to ±0.1 mg/L. It can be powered by a current ranging from 3.0 to 5.0 volts. The sensor requires periodic calibration to ensure optimal accuracy and can be calibrated using standard oxygen calibration solution. To connect the sensor with Arduino, the "DFRobot$_{O}xygenSensor.h$"

library is used, providing easy-to-use commands for reading oxygen data from the sensor, simplifying the integration process and ensuring accurate oxygen level measurements.

Figure 22: oxygen Sensor

Input voltage	3.3 - 5 V
Pressure	0 - 50 PSI.
Measuring range	0 - 20 mg/L
Operating temperature	0 - 40 ℃
Response time	90 seconds

Table 4: Dissolved Oxygen Sensor[58]

5.2.4 The breadboard

The role of the breadboard in the aquaculture project lies in providing a platform for building and assembling electronic circuits used in the smart aquaculture system. The breadboard enables easy and flexible connection and installation of sensors and electronic modules such as Arduino or Raspberry Pi. This efficient tool allows for testing and experimenting with connections and circuits before final implementation, facilitating the development and integration process to achieve effective and sustainable improvements in the aquatic environment for breeding aquatic organisms.

This efficient tool allows for testing and experimenting with connections and circuits before final implementation, facilitating the development and integration process to achieve effective and sustainable improvements in the aquatic environment for breeding aquatic organisms.

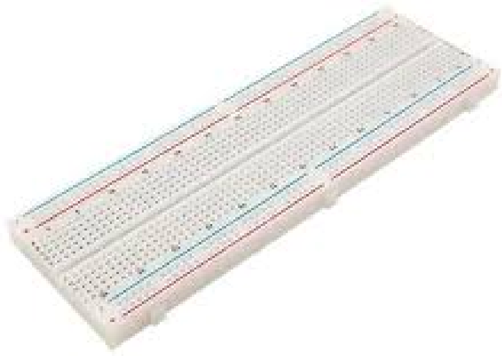

Figure 23: The breadboard

5.2.5 The jumper wires:

Wiring plays a vital role in the smart aquaculture project by facilitating essential electrical connections between different system components. It links sensors to control units like Arduino to transmit environmental readings, supplies power to sensors and control units, and transfers collected data to the cloud analysis platform via the network communication module. Good wiring ensures stable and reliable connections, protects data from interference, and offers flexibility in customizing connections and modifying the system. In summary, wiring is the fundamental factor ensuring the system operates efficiently and effectively, contributing to improving the aquatic environment for the growth of aquatic organisms.

Figure 24: The jumper wires

5.2.6 USB cable:

The USB cable plays a crucial role in the smart aquaculture project, serving as a vital link for communication and power transmission between different components. It connects devices such as Arduino to a computer or power source, allowing data transfer for tasks like programming, debugging, and configuration. Moreover, it supplies power to these devices, ensuring their continuous operation during data collection and processing. The USB cable's function is essential in maintaining connectivity and power supply, which are critical for the seamless operation of the system and the efficient management of aquatic environments.

Figure 25: USB cable

4.6 Software Components

Programming node red: Node-RED is an open-source software tool developed by IBM for creating workflows visually using the Node.js runtime and JavaScript. Node-RED allows users to connect devices, services, and interfaces through a graphical user interface based on drag-and-drop, simplifying the development process without requiring extensive coding. It supports numerous common protocols such as HTTP, MQTT, and WebSockets, making it suitable for a wide range of applications, especially in the Internet of Things (IoT) field. Users can also create custom nodes using JavaScript to meet their specific needs, benefiting from a large library of ready-to-use nodes and extensive community support. Node-RED is installed via Node.js, and after installation, it can be launched and accessed through a web browser interface. Widely used in IoT projects, system integration, and automation and control of devices, Node-RED is a powerful and flexible tool that enables developers to create advanced solutions in a simple and efficient manner.

Programming xAMPP

XAMPP is an open-source software package that provides an easy-to-use integrated development environment for running and managing web applications locally. The acronym XAMPP stands for Cross-Platform (X), Apache (A), MySQL or MariaDB (M), PHP (P), and Perl (P). It combines these essential components to create a robust web development environment that can be installed quickly on Windows, Linux, and macOS. XAMPP is popular for its ease of installation and management, featuring a graphical control panel for managing Apache, MySQL, and other services. It is widely used by developers to create and test web applications locally before deploying them to live servers, and it serves as an educational tool for teaching web development and database management. XAMPP allows developers to place their web project files in the htdocs directory and access them via http://localhost in a web browser. By offering a powerful and flexible environment, XAMPP simplifies the process of setting up a local web server, enabling developers to focus on building and testing their applications efficiently.

Programming Laravel:

Laravel is an open-source, powerful PHP framework used for web application development, providing an advanced yet user-friendly development environment. It boasts numerous advanced features such as advanced routing system, caching system, Eloquent ORM, middleware system, security features, templating, and testing capabilities. Widely utilized, Laravel is employed for developing a diverse range of web applications including blogs, e-commerce stores, and content management systems, and is favored for its scalability and security, making it a preferred choice for large-scale websites and social networking applications.

4.7 Software Implementation

To achieve success in the field of aquaculture, farmers need advanced tools that help them improve production quality and operational efficiency. This is where Laravel comes in—a powerful and versatile PHP framework known for its simplicity, elegance, and ease of use. Laravel is one of the leading tools in modern web application development, offering a wide range of features that make the development process fast and efficient. By using Laravel, developers can create an intelligent aquaculture system that leverages IoT (Internet of Things) technologies and artificial intelligence to enhance the environmental conditions for aquatic organisms. Laravel contributes to this goal by providing a flexible and scalable infrastructure that facilitates the collection, processing, and analysis of data. Additionally, Laravel easily supports the integration of APIs, allowing sensors and smart devices to be seamlessly incorporated into the system. With these capabilities, farmers can utilize a comprehensive system that provides precise analytics and real-time recommendations.

Here are some basic steps by which our intelligent system was created in Laravel:

The basic steps to create a login and registration system in Laravel:

A login and registration system is an essential part of many web applications, allowing users to sign up (create an account) and log in to access features specific to registered users. In Laravel, the login and registration system is provided through a set of built-in tools and features that make the implementation process easy and quick.

After installing Laravel and configuring the database settings in the .env file, we ran the migrations to create the necessary tables for user authentication. Next, we installed the Laravel Breeze package, which provides the basics of authentication, allowing us to set up a login and registration system easily and quickly. We used this system as part of a smart aquaculture application, which enables users to create accounts and log in to access advanced and efficient features related to the aquaculture system.

This data is then transmitted to the Node-RED program on the computer via the serial port.

Receiving and Processing Data Using Node-RED:

We used the Node-RED program to receive data from the Arduino, process it, and display it as live charts on the program's dashboard . To draw the chart in Node-RED, we used the ui-chart. node, which is part of the Dashboard node. The process involved dragging the ui-chart . node from the sidebar to the workspace, configuring it by selecting the obtained data and customizing the appearance of the chart (such as in the form of arc). Then, we connected the data source (Arduino) to the ui-chart. node and deployed the flow. Afterwards, we accessed the Node-RED dashboard to view the generated chart and displayed it on the program's Dashboard.Figure shows illustrates the method on Node-RED:

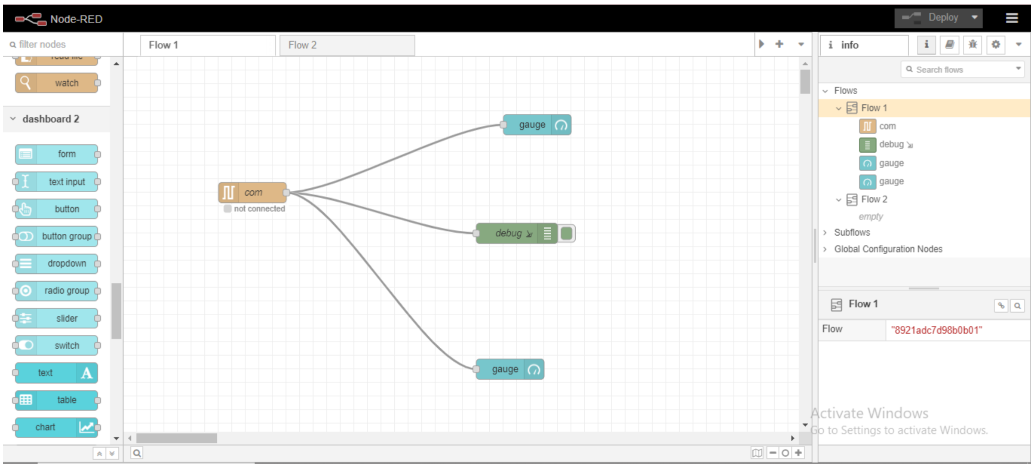

Figure 26: illustrates the method on Node-RED

Database Using XAMPP:

XAMPP is an integrated development environment that includes an Apache server, MySQL database, and PHP. It is used to store user data securely and systematically in the database when users access the website. We start by clicking start in Apache and MySQL Figure shows the database of some of those registered in our program

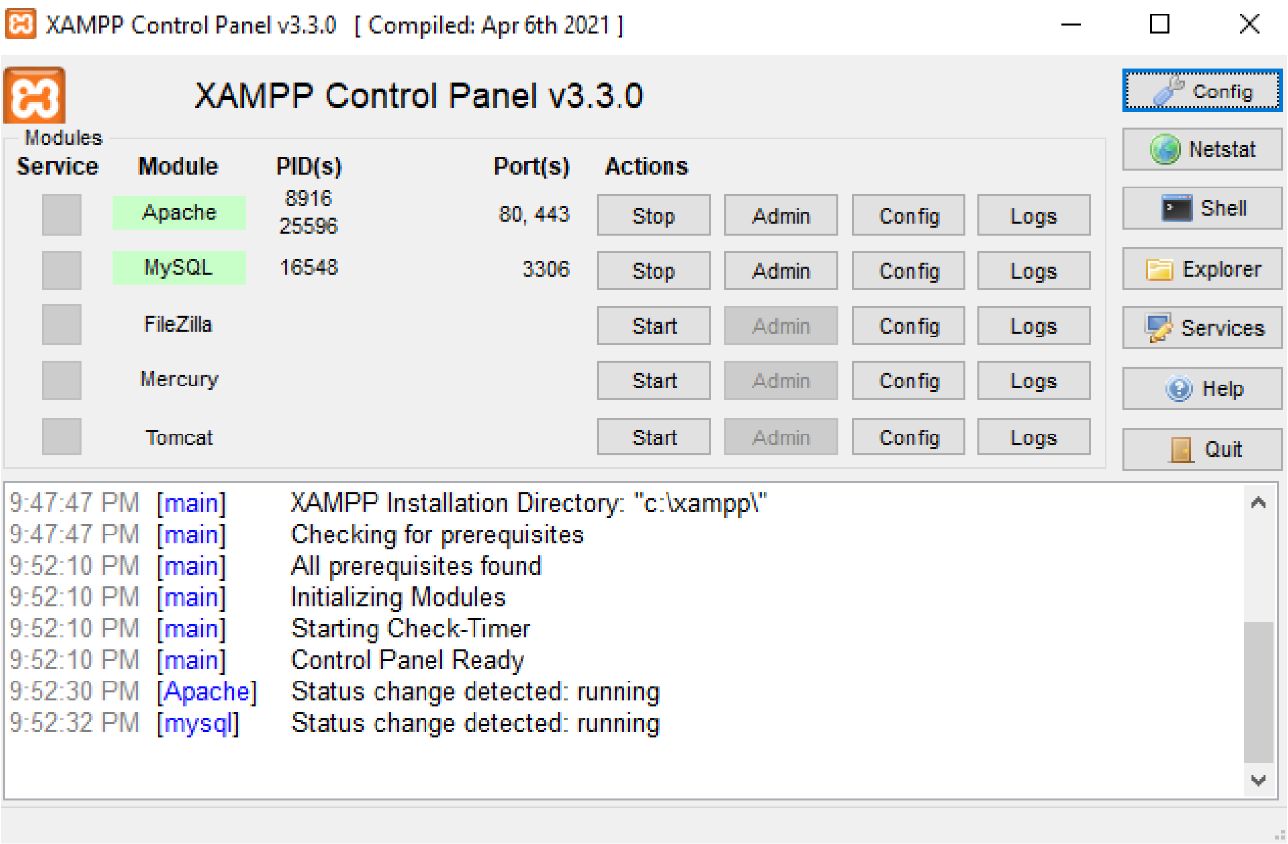

Figure 27: XAMPP program

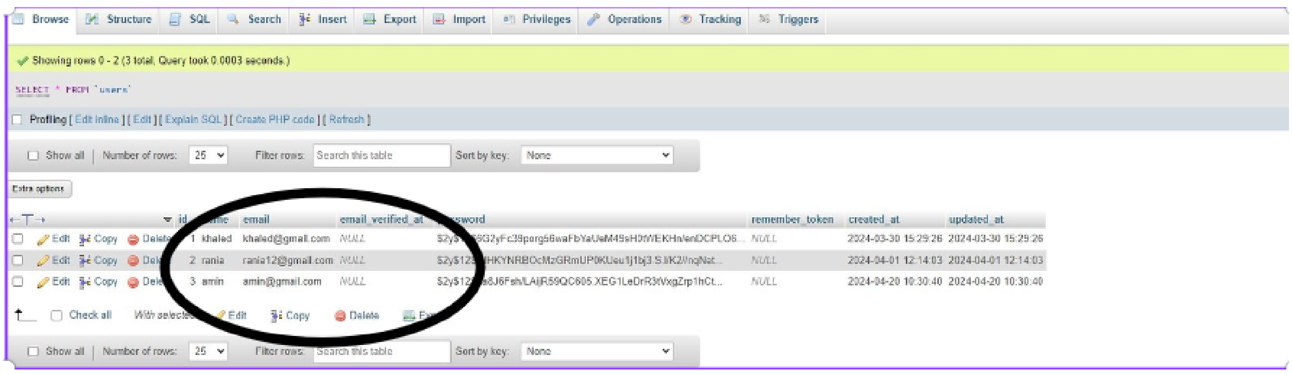

Figure 28: Database

The main interface of the program(Home Page):

The main interface of the program (Home Page) welcomes visitors and provides an overview of the content and available services. The aquaculture site features a well-designed, user-friendly interface with rich informational content and high-quality images. The site logo, "Aquaculture," appears at the top left, and the top navigation bar includes key options such as Home, Dashboard, About Us, Services, Pricing, Contact, Login, and Register. The interface includes a large background image depicting a modern aquaculture farm with a large fish tank, sensors, and other equipment. A prominent "Get Started" button is centered on the page, directing users to a page with information on how to use the company's precise aquaculture services.

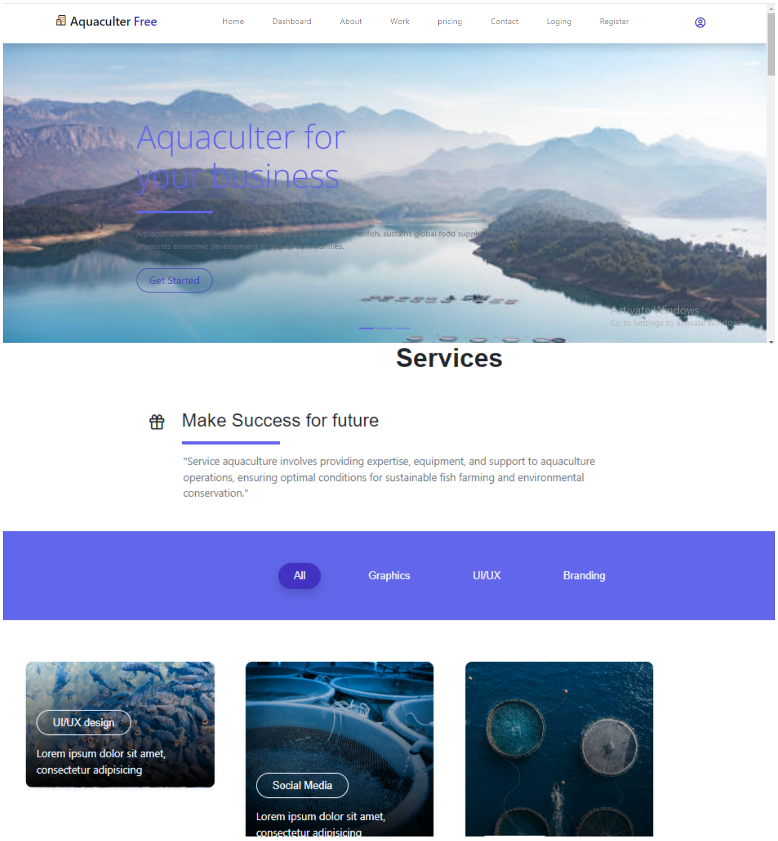

Figure 29: Home Page

The main interface of the intelligent aquaculture program serves as a comprehensive gateway that welcomes visitors and provides an overview of the available content and services. It features a well-designed and user-friendly layout, combining rich information and high-quality images. The interface acts as a central entry point for users, facilitating access to content and services while providing an integrated user experience. It aims to improve the user experience, ease access to various sections of the site, and enhance knowledge with rich informational content, making it a valuable tool for farmers, researchers, managers, and environmental engineers who seek to improve aquaculture operations using advanced technologies. The interface strives to promote environmental sustainability and increase productivity by offering a central platform that supports effective communication and provides accurate information and integrated services.

Loge in page:

This page is the registration page. This page is used to create new user accounts. The page typically includes two fields:

Username: A unique identifier for the user.

Password: A string of characters or numbers used to verify the user's identity.

Email: Used to send confirmation messages and other information to the user.

First Name: The user's first name.

Last Name: The user's last name.

This page is the login page. This page is used to allow users to access their accounts on a website or computer system.

The page typically includes two fields:

Username: A unique identifier for the user.

Password: A string of characters or numbers used to verify the user's identity.

The page may also include other options, such as:

Remember Me: If this option is selected, the website or computer system will save the user's username and password so they do not have to enter them again each time they browse the site or use the system.

Forgot Password?: This link provides a way for users to recover their password if they forget it.

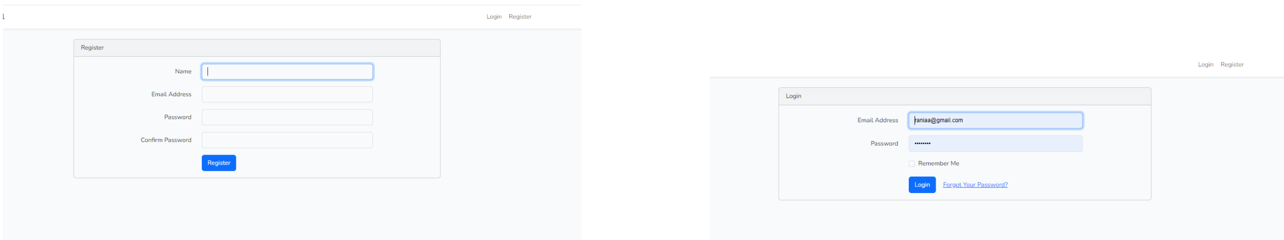

Figure 30: Loge in page

Registration Page:

The registration page in the smart aquaculture system serves as a vital interface allowing users to create new accounts to access the system. This page acts as the initial step in the user experience, enabling users to input their personal information such as username, password, email, first name, and last name. Its primary role is to verify user identity and ensure data security by establishing unique identifiers and passwords. The page enhances system security, facilitates account management, and provides a seamless user experience. It is utilized by farmers, researchers, managers, and environmental engineers seeking efficient management of aquaculture operations. The goal of the registration page is to provide a secure and user-friendly method for users to establish new accounts, thereby enhancing data security and providing an integrated user experience. Its importance lies in serving as the starting point for user interaction with the system, ensuring accurate user registration and effective management.

Login Page:

The login page in the smart aquaculture system is a fundamental interface allowing users to access their accounts within the system. This page verifies user identity through username and password input. Additionally, it offers options such as "Remember Me," which saves login information for future access, and "Forgot Password?" to facilitate password recovery. Its role is to ensure that only authorized users can access the system, enhancing data security and protecting sensitive information. Benefits include easy system access, improved user experience through login options, and enhanced system security. The login page is used by the same target audience as the registration page, including farmers, researchers, managers, and environmental engineers. Its goal is to provide a secure and streamlined method for users to access their accounts, ensuring system security and ease of access to information and functionalities. Its importance lies in restricting system access to authorized users, thereby maintaining data security and privacy.

Health table page

The image shows a page from the intelligent aquaculture system software titled "Health table". This page is a data entry form designed to record medication information for the aquaculture system.
Page Components

Date: A field for entering the date using the format mm/dd/yyyy, allowing the user to specify the exact date of medication administration.
Time: A field for entering the precise time using a time picker, ensuring accurate tracking of when the medication was administered.
Type of Medication: A text field for entering the type of medication given to the aquatic organisms, helping in categorizing and managing different types of treatments.
Designation: A text field for entering a specific label or description of the medication, aiding in detailed record-keeping and identification.
Quantity: A text field for entering the amount of medication administered, which is crucial for dosage tracking and ensuring proper treatment.
Submit Button: The "Submit" button is used to submit and record the entered data into the system, allowing for immediate updating of medication records.

This table plays a vital role in the intelligent aquaculture system by providing an organized and user-friendly interface for recording medication data. Accurate tracking of medication types, dosages, and administration times is essential for maintaining the health and well-being of the aquatic organisms. This data helps in monitoring the effectiveness of treatments, preventing over- or under-medication, and ensuring compliance with health and safety standards. By recording this information, the system can better manage and optimize the health care of the aquatic environment, contributing to the overall success and sustainability of the aquaculture operation.

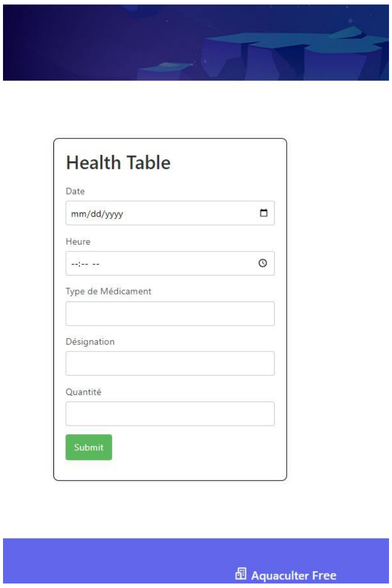

Figure 31: Health Table

Food table page

The image shows a page from the intelligent aquaculture system software titled "Aquaculter Free". This page is a data entry form designed to record and monitor the feeding of fish or aquatic organisms in aquaculture systems.

Page Components

Date and Time: the date field allows the user to select the current date or specify a specific date using a calendar.

The time field allows the user to set the exact time for recording feeding data.

Type of Food: A dropdown menu to select the type of food provided to the aquatic organisms (in this case, "Vegetable" is selected).

Quantity: A text field to enter the quantity of food provided, which helps in accurately monitoring and recording the amount of food. Observations: A text field to add any notes or comments related to the feeding process or the condition of the aquatic organisms, providing additional details that may be important for managing the system.

Submit Button: The "Submit" button is used to submit and record the entered data into the system, allowing for immediate updating of records.

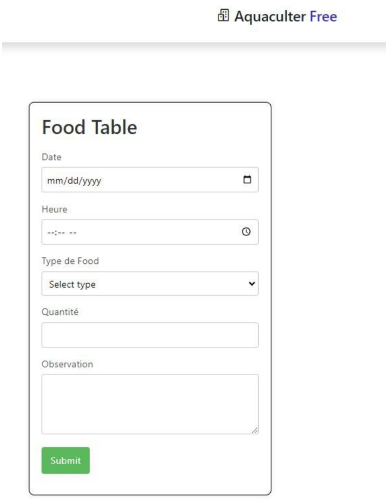

Figure 32: Food Table

This table plays a vital role in the intelligent aquaculture system by providing an easy and organized way to record daily feeding data. This data helps improve feed management and ensures the appropriate quantities and types of food are provided to the aquatic organisms, contributing to their health and growth. Additionally, the added observations allow for monitoring the general condition of the aquatic organisms and quickly identifying any issues that may arise, enhancing the system's efficiency and sustainability.

Purchasing table page

The image shows a page from the intelligent aquaculture system software titled "Purchasing Input Form". This page is a data entry form designed to record purchase transactions related to aquaculture systems.
Page Components
Date: A field for entering the date using the format mm/dd/yyyy, allowing the user to specify the exact date of the purchase.
Type: A text field for entering the type of item purchased, whether it is fish feed, equipment, or other necessary materials for the system. Designation: A text field for entering a label or description of the purchased item, which helps in better identifying the materials.
Quantity:A text field for entering the quantity of the purchased item, aiding in inventory control and management.
Price: A text field for entering the price of the purchased item, helping in tracking costs and financial expenditures.
Submit Button: The "Submit" button is used to submit and record the entered data into the system, allowing for immediate updating of records.

This table plays an important role in the intelligent aquaculture system by providing an easy and organized way to record purchase data. This data helps improve resource management and ensures the continuous availability of necessary materials. Additionally, recording quantities and prices helps track costs and manage the budget

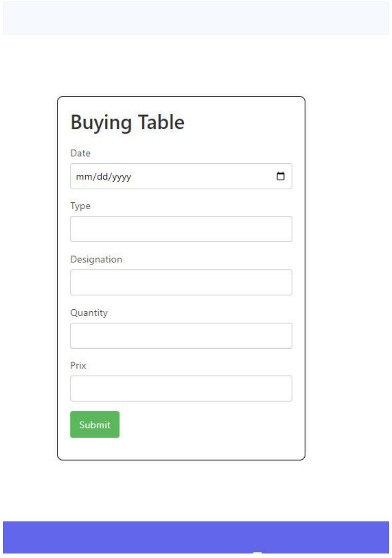

Figure 33: pushen Table

more effectively, enhancing the system's efficiency and sustainability.

Incident table page

The image shows a page from the intelligent aquaculture system software titled "Problemes Input Form". This page is a data entry form designed to record problem information related to the aquaculture system.

Page Components

Date: A field for entering the date using the format mm/dd/yyyy, allowing the user to specify the exact date when the problem was identified.

Time: A field for entering the precise time using a time picker, ensuring accurate tracking of when the problem was noticed.

Type of Problem: A text field for entering the type of problem encountered in the aquaculture system, helping in categorizing and managing different types of issues.

Description: A text field for entering a detailed description of the problem, aiding in comprehensive record-keeping and identification.

Severity: A drop-down menu for selecting the severity level of the problem (e.g., Low, Medium, High), which is crucial for prioritizing responses and actions.

Submit Button: The "Submit" button is used to submit and record the entered data into the system, allowing for immediate updating of problem records.

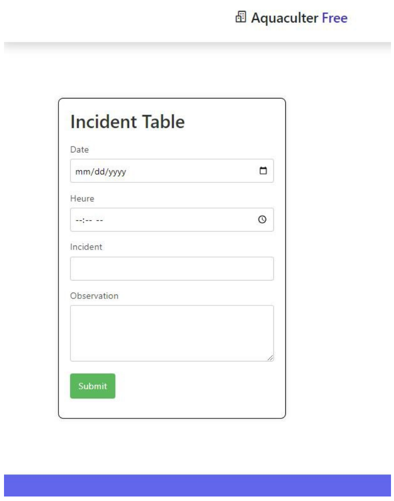

Figure 34: Incident Table

This table plays a vital role in the intelligent aquaculture system by providing an organized and user-friendly interface for recording problem data. Accurate tracking of problem types, descriptions, and severity levels is essential for maintaining the health and operational efficiency of the aquaculture environment. This data helps in monitoring recurring issues, identifying patterns, and implementing timely solutions, which are crucial for preventing disruptions and ensuring the smooth functioning of the aquaculture system. By recording this information, the system can better manage and address problems, contributing to the overall success and sustainability of the aquaculture operation.

Dashboard

The Dashboard, or Control Panel, is a graphical user interface typically composed of multiple interface elements displaying important information and providing users with easy access to various functions. Dashboards are commonly used in web applications to manage and display data in an organized manner, providing tools for controlling and supervising the system or application. Basic Components of the Dashboard: A set of charts or a series of curves to represent data.
This Dashboard is designed to monitor and control the vital characteristics of the aquatic environment. The following are displayed on the dashboard
Date and Time:
Temperature , pH end oxg
Health Status:
The following illustration demonstrates that in the event of any undesirable change, such as a variation in a key factor or water property, an alert signal will be sent. This will be manifested by a change in the chart where the indicator rises, accompanied by a warning message displayed.

The Dashboard, also known as the Control Panel, is a graphical user interface typically composed of multiple elements displaying critical information and providing easy access to various functions. Dashboards are commonly used in web applications to manage and present data in an organized manner, offering tools for system or application supervision and control. Key components of the Dashboard include a set of charts or graphs that simplify data representation. This Dashboard is specifically designed to monitor and control vital characteristics

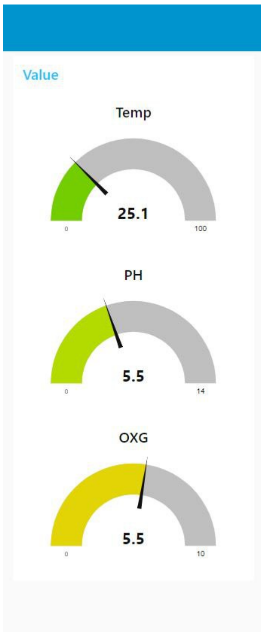

Figure 35: Dashboard

of the aquatic environment, typically displaying: Date of measurements. Current temperature. Overall health status of the aquatic environment. The Dashboard functions to provide a direct and effective visual display of data, facilitating administrators and end-users in monitoring the current system status comprehensively. It is utilized by farmers, researchers, environmental engineers, and project managers who require precise environmental insights to make informed decisions. The goal of the Dashboard is to enhance the management and monitoring of aquatic environments, ensuring sustainability through organized and accurate data presentation. Its importance lies in facilitating access to critical information and prompt decision-making, thereby improving the efficiency of aquaculture operations and promoting overall environmental and economic sustainability of the system.

4.8 Testing

Scenario 1: Temperature Monitoring

Description: Monitoring the water temperature to ensure it remains within the optimal range.

Simulated Data: Temperatures generated between 15 and 30°C.

Analysis: Use of algorithms to detect anomalies when the temperature falls outside the optimal range (20-25°C). In case of temperature changes:

- If the temperature drops below 20°C: the heating system is activated and the vent protection device opens.

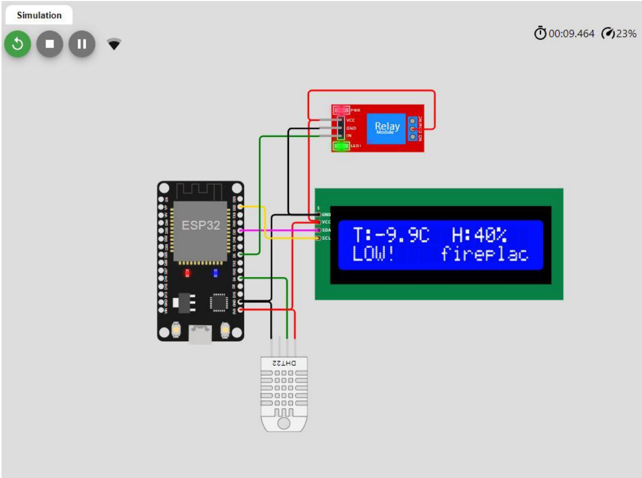

Figure 36: Activating the heating system

- If the temperature rises above 25°C: the cooling system is activated to lower the temperature to the optimal range.

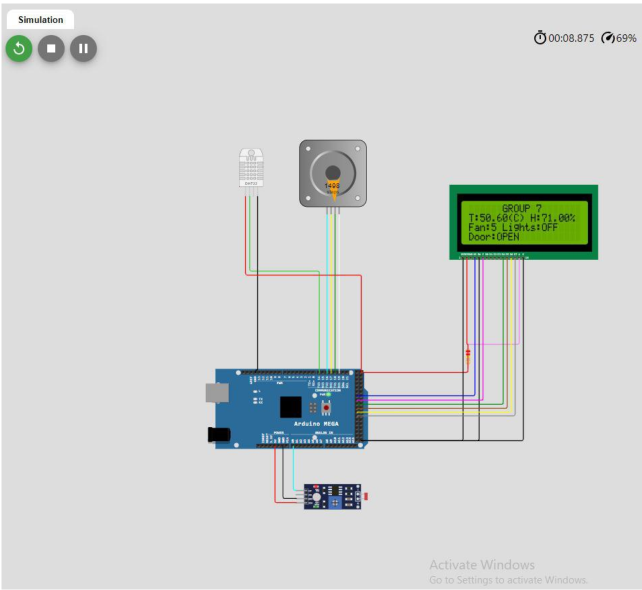

Figure 37: Activating the cooling system

Scenario 2: pH Control

Description: Monitoring and adjusting the pH to maintain a healthy environment for the fish.
Simulated Data: pH values generated between 6.5 and 8.5.
Analysis: Detecting sudden pH variations and activating correction systems when values fall outside the optimal range (7.0-7.5).

In case of pH changes:

- If the pH drops below 7.0: the pH correction system is activated to raise the pH to the optimal range.
- If the pH rises above 7.5: the pH correction system is activated to lower the pH to the optimal range.

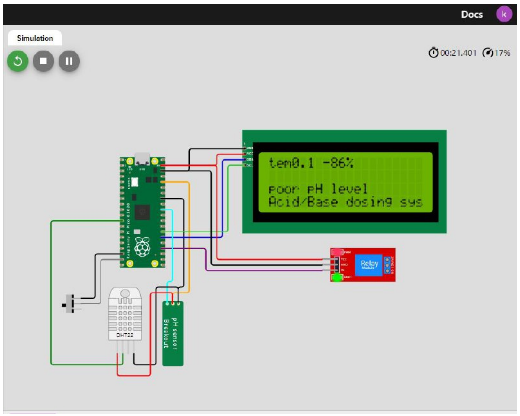

Figure 38: Activating the pH correction system

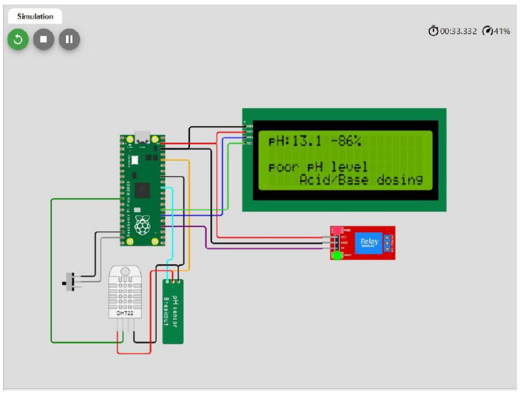

Figure 39: Activating the pH correction system

Scenario 3: Salinity Monitoring

Description: Monitoring and adjusting the salinity level in the water to ensure a suitable environment for aquatic organisms.
Simulated Data: Salinity levels generated between 1 and 5 parts per thousand (ppt). Analysis: Use of algorithms to detect sudden changes in salinity and activate adjustment systems when the level falls outside the optimal range (2-3.5 ppt).
In case of salinity changes:

- If the salinity drops below 2 ppt: the salinity correction system is activated to increase the salinity to the optimal range.
- If the salinity rises above 3.5 ppt: the salinity correction system is activated to lower the salinity to the optimal range.

Scenario 4: Oxygen Monitoring

Description: Monitoring and adjusting the dissolved oxygen level in the water to maintain a healthy environment for aquatic organisms.
Simulated Data: Dissolved oxygen levels generated between 4 and 10 mg/L.
Analysis: Use of algorithms to detect anomalies in oxygen levels and activate aeration systems when the levels

fall outside the optimal range (6-8 mg/L).

In case of oxygen level changes:

- If the oxygen level drops below 6 mg/L: the aeration system is activated to increase the oxygen level to the optimal range.
- If the oxygen level rises above 8 mg/L: the aeration system is activated to lower the oxygen level to the optimal range.

4.9 Data Analysis

The data analysis process for the intelligent aquaculture system involves several sequential steps aimed at understanding and improving water quality and ensuring operational sustainability. This process heavily relies on the Internet of Things (IoT), which is a fundamental component of the system. The process begins with the collection of integrated data from multiple sensors monitoring vital parameters such as temperature, pH levels, and dissolved oxygen. This data is effectively transmitted to the main control center or the cloud for remote analysis and monitoring.

Using statistical analysis tools and advanced techniques, the data is deeply explored to understand temporal trends and underlying patterns. Anomaly detection are also applied to identify any unusual changes in the sensor data, aiding in the early identification of issues that require immediate attention.

We have displayed sensor data on our smart system's dashboard after successfully transmitting it from the sensors via the simulator. the graphs include changes in water temperature, pH value, salinity, and dissolved oxygen. This data reflects the stable state of the aquatic environment by displaying the normal and appropriate values for each of these parameters.

4.10 Disscussion

This comprehensive and integrated approach, the system excels in providing an optimal aquatic environment for the growth of marine organisms and the overall health of the ecosystem. This strategy is a fundamental part of the intelligent management of the aquaculture system, as it contributes to environmental sustainability and improves operational efficiency. This leads to the effective and sustainable management of environmental resources.

Operational Efficiency:

The automated control capabilities reduce the need for constant manual intervention by farmers. This automation not only saves time but also ensures that the water quality remains within optimal ranges at all times, enhancing the overall productivity of the aquaculture system.

Improved Decision-Making:

With the data being continuously monitored and logged into a cloud-based database, farmers have access to historical and real-time data. This information is crucial for making informed decisions regarding feeding, medication, and general pond management. Our system includes comprehensive tables for feed, medication, and incidents, which helps farmers track and manage these aspects efficiently.

Enhanced Productivity and Profitability:

By maintaining optimal water quality conditions, the risk of disease outbreaks and fish mortality is significantly reduced. This leads to healthier and faster-growing fish, ultimately increasing productivity and profitability for the farmers.

Alerts and Notifications:
The system is also equipped to send alerts and notifications in case of any anomalies, ensuring that farmers can take immediate action to address potential issues. This feature is particularly beneficial for preventing disasters and minimizing losses.

The intelligent aquaculture system represents a significant advancement in sustainable management of aquatic environments, relying on the Internet of Things (IoT) to monitor and analyze critical environmental parameters such as temperature, pH levels, dissolved oxygen, and salinity. The system begins by collecting and cleaning data to ensure accuracy, followed by in-depth analysis using advanced statistical tools and anomaly detection algorithms to identify trends and unusual changes. One of the key features is real-time alerting, which activates alarms and visual cues when predefined thresholds are exceeded, enabling rapid response from the specialized team. The dashboard displays data interactively and visually, facilitating informed decision-making. This system improves environmental monitoring and control, enhances operational efficiency, enables early issue detection, promotes sustainability and resource management, and supports regulatory compliance. With this comprehensive approach, the system provides an optimal aquatic environment for the growth of marine organisms and ensures the long-term sustainability of environmental resources.

4.11 Conclusion

In conclusion, the intelligent aquaculture system represents a significant advancement in improving production quality and operational efficiency in aquaculture. By leveraging IoT technologies and artificial intelligence, this system provides precise analytics and real-time recommendations, enhancing the environmental conditions for aquatic organisms and ensuring maximum productivity. The system offers a flexible and scalable infrastructure that enables efficient data collection and processing, seamlessly integrating smart devices and sensors. Utilizing advanced technologies like Laravel and Node-RED allows for the creation of user-friendly interfaces and effective monitoring and analysis processes. This contributes to the sustainability of aquaculture and improves the quality of marine products. With this technology, farmers can achieve new levels of efficiency and productivity, utilizing modern technology to meet their environmental and economic goals.

Chapter 05

5 General Conclusion

5.1 Conclusion

In concluding our journey through the Internet of Things (IoT) revolution in aquaculture, we can confidently say that this technology has opened endless horizons for this vital field.
IoT has become a smart window overlooking the world of aquaculture, enabling us to better understand the needs of fish and interact with them in a scientifically precise manner.
Aquaculture is no longer solely reliant on the intuition and experience of farmers but has evolved into a precise science managed by artificial intelligence. It analyzes data, extracts knowledge from it, and guides fish farmers towards the best practices to achieve the highest levels of productivity.
The benefits of IoT extend beyond improving productivity; they also include enhancing sustainability by reducing resource consumption and environmental impact, improving the quality of the final product, and enhancing food security worldwide.
With IoT, the future of aquaculture is no longer unknown but rather illuminated with promising opportunities, heralding a new era of abundance and self-sufficiency.
However, like any scientific revolution, the journey of IoT is not without its challenges. There is still much work to be done to develop this technology further and expand its application.
Nevertheless, with determination and perseverance, there is no doubt that we can overcome these challenges and turn IoT into a revolutionary tool that brings about a qualitative leap in the field of aquaculture, contributing to building a better future for humanity and the environment.
Together, we can turn the IoT revolution into a tangible reality, making aquaculture a rich source of food and prosperity for future generations.

5.2 Perspectives :

The perspective of the smart system Aqualink in aquaculture lies at the intersection of aquaculture, technology, and data analytics. It represents a transformative approach to aquaculture by leveraging advanced technology and IoT techniques to improve aquaculture practices and increase productivity:
1- Precision Aquaculture: The smart system embodies the principles of precision aquaculture, focusing on increasing productivity, improving the quality of aquatic products, reducing production costs, and enhancing profitability while also improving fish health and welfare. Aquaculturists can make precise, data-driven decisions tailored to the specific needs of aquatic organisms. This approach increases the efficiency of water resource utilization, reduces waste, and ensures optimal development of the field.
2- Data Collection: The smart system leverages data analytics and artificial intelligence to provide valuable analyses and recommendations. By analyzing vast amounts of data from diverse sources, aquaculturists gain a deeper understanding of the appropriate environment for aquatic life, enabling them to provide suitable conditions based on real-time and historical data. This data-driven approach enhances production efficiency and productivity.
3- Real-Time Monitoring and Intervention: The system enables real-time monitoring of aquacultural conditions, including temperature, oxygen levels, and humidity. This allows for the detection of changes or problems and prompt response. By providing alerts and notifications, the system empowers aquaculturists to take immediate action, preventing potential losses of aquatic organisms and optimizing returns.

4- Risk Mitigation and Resilience: The smart system helps mitigate risks associated with diseases, pollution, or adverse environmental conditions that could affect aquatic organisms. By providing accurate aquatic forecasts, early detection of unexpected changes, and disease monitoring, it enables aquaculturists to implement preventive measures and take timely corrective actions. This enhances the resilience of aquaculture operations and reduces financial losses.

5- Accessible and User-Friendly Technology: The smart system aims to make advanced technology accessible and user-friendly for aquaculturists. User-friendly interfaces, mobile applications, and simplified visualizations enable easy interaction with the system and understanding of the analyses and recommendations provided. This ensures that technology adoption is not a barrier and empowers aquaculturists of all backgrounds to leverage the benefits of smart aquaculture.

5.3 The Future of smart Aquaculture

Smart aquaculture is still a relatively new field, but it has the potential to revolutionize the aquaculture industry. As these technologies continue to develop, we can expect to see even more innovation and progress in the years to come.

The future of smart aquaculture holds great promise for transforming fish production methods, addressing environmental concerns, and enhancing efficiency. This future includes advanced monitoring systems that collect real-time data on water quality, fish behavior, and ecosystem health. Automation and robotics will play a significant role in streamlining tasks such as feeding, monitoring, and harvesting, thus improving efficiency and reducing labor costs. Integration of data analytics and agricultural artificial intelligence will enable data-driven decision-making to optimize production. Smart aquaculture will prioritize sustainability by minimizing environmental impact and resource use, while also focusing on vertical integration and traceability for quality and safety assurance.

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