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IR4.0 Technologies Upskilling Framework to Enhance Marine Aquaculture Production

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***Abstract*—Enhancing aquaculture production systems can contribute to meeting several Sustainable Development Goals of the National Union, such as SDG 1, Zero Hunger, and SDG 14, Life below Water. The traditional methodologies used in aquaculture face several challenges that negatively affect the quality and quantity of the harvested fish. The objective of this research paper is to investigate the various challenges faced in the marine aquaculture industry and how IR4.0 technologies can mitigate these challenges to enhance production and promote sustainable aquaculture. A collaborative research methodology is followed to achieve the objectives of the research. From this perspective, a framework based on triple-helix is proposed, consisting of a collaboration between industry, academia, and government. A Blue Water Fishery Company case study has been considered to analyze the real-time challenges they faced in the existing aquaculture farm in the Sultanate of Oman. Sustainable solutions based on technology are not just static products for a fixed requirements set. Technology is evolving significantly when solving a dynamic environment such as aquaculture. To achieve this, the proposed framework considers upskilling the national youth. This will build the capacity to solve various challenges through IR 4.0 technologies, such as IoT, AI, and Big data, resulting in Smart fisheries industries.**

Keywords—fish farming, IR4.0, R&D framework

I. INTRODUCTION

Aquaculture in freshwater or marine environments involves carefully cultivating and maintaining aquatic organisms like fish, mammals, and plants. It's a source of marine life, such as seafood, bait, sports, crabs, aquarium fish, fish eggs, seaweed, and vegetable harvests. The aquaculture industry has the most significant potential for rapid expansion of any food industry worldwide. More than half of humans eat aquatic foods from this ecosystem, making it crucial to world food production. The FAO's aquaculture work is based on the Blue Transformation vision, which aims to improve human, social, cultural, and environmental well-being while reducing environmental impacts, improving biosecurity and disease control, and building capacities to ensure decent and reasonable outcomes [1]

One of the primary objectives outlined in the Oman Vision 2040 [2] is establishing a world-class ecologically sustainable fishing sector that can significantly contribute to Oman's economy. The objective of Vision 2040 has been drawn from the preceding Vision 2020, which emphasizes the role of the private sector in spearheading the growth of capital and jobs within the fisheries sector. The estimated GDP of the fisheries sector, which stands at 165 million OMR, fails to reflect the actual value of the business accurately. This is primarily due to its failure to consider the significant contributions made by processing, marketing, and logistics activities within the fisheries value chains. The first anticipated capital of the fisheries business amounts to 380 million OMR. Further endeavors are required to precisely delineate and monitor the economic magnitude and significance of the industry. The primary focus of Vision 2040 is to enhance the governance of Oman's domestic fisheries to improve the overall monetary value. This objective is achieved through several means, such as maintaining environmental sustainability, generating possibilities for private investment, promoting innovation to enhance Omani value chains, and increasing the value of fish products. According to projections, the aquaculture industry in Oman is expected to achieve an annual production of 33,700 tons, resulting in a turnover of OMR71.5 million over the next decade. Furthermore, by 2040, the sector is expected to grow substantially, reaching a production capacity of 220,000 tons, with an estimated OMR770 million.

During the forecast period (2023-2028), the Oman Fisheries and Aquaculture Market is expected to increase from USD 0.60 billion in 2023 to USD 0.81 billion by 2028, at a CAGR of 6.20% [3]

II. THE CRITICAL CHALLENGES

To achieve the targets mentioned in the previous section, it is required to increase aquaculture production based on the increased demands. Aquaculture farming can be done in small or large ponds confined to a limited area; therefore, its operations can be controlled and monitored with some effort. Aquatic animals can also be cultivated as offshore farming, where the aquatic farms, mostly fish farms, are built in the sea near shore. Since these farms are developed in the natural seawater, they face many challenges in operating and maintaining such marine fish farms. This paper focuses on the improvement in marine aquaculture farming and production.

The challenges faced by offshore farming can be classified into environmental, operational, and design challenges. Environmental challenges include water depth, current velocity, wave action, seabed conditions, and adverse weather and storms. Although deeper water provides high benefits for fish farming in terms of reduced waste sediment and more space for fish movement, it also increases the costs of anchoring and mooring systems.

[4]A crucial challenge in the operation of fish farming is ensuring a suitable environment for the well-being of the fish. This involves regulating the five main factors affecting their survival: water quality (dissolved oxygen, salinity, temperature, pH, turbidity, pollution, etc.), stocking density (net water volume), feed frequency, feed time, minimal movement, and reduced net deflection (affected by current, wind, waves, pen design). Apart from building appropriate infrastructure for the fish farm, the industry faces other operational challenges, including collisions between vessels and fish pens and invading marine animals. One of the challenges in designing offshore fish pens is the need for more experience and comprehensive design guidelines.

III. OVERVIEW AQUACULTURE INDUSTRY(BACKGROUND)

The adoption of Industry 4.0 (IR 4.0) technologies is revolutionizing the field of fish farming and aquaculture, offering innovative solutions to address the numerous challenges faced by this vital industry. In the face of rising global demand for seafood and the increasing strain on natural resources, IR 4.0 technologies have emerged as a transformative force. This section discusses previous work on using IR4.0 technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, etc., to improve fish farming and aquaculture by addressing the challenges discussed in the previous section. This section provides an overview of the latest recent research efforts focused on leveraging IR4.0 technologies to enhance the fish farming industry with the aid of IR4.0 technologies.

IoT-based aquaculture system to enhance and monitor water quality for fish farming is proposed in [5]. The system considers the water's temperature, pH, oxygen content, and dissolved ammonia concentration to provide a more productive and long-lasting aquatic ecosystem. The paper's most vital points are its ability to boost fish productivity, add to the national economy through exports, and better the lives of fish farmers. The report does concede that there is a lack of Android mobile app functionality, but it does recommend that future work investigate integrating with iOS-based apps.

In [6], the author presents the results of a thorough investigation of using an Internet of Things-based system for continuous, real-time fish farm monitoring and management. This work's greatest strength is the comprehensiveness with which it describes the system architecture, down to the hardware and software components and the integration of numerous sensors and actuators for tracking water quality and ambient conditions. The experimental results presented in the publication verify the system's efficacy and precision. However, the research lacks a comparative analysis with current fish farming monitoring systems and further discussion on the suggested system's scalability and cost-effectiveness.

In [7], the authors suggest and demonstrate a novel method for automating fish farming using IoT technology. The study excels in examining and using a wide range of sensors and actuators for controlling and maintaining critical environmental conditions for fish production, including temperature, pH, turbidity, and water level. Adding the Arduino UNO microcontroller board with LoraWan communication technology improves the system's efficacy and allows it to be expanded. However, the study lacks essential specifics on the methods used to acquire and analyze the data. The potential technical difficulties and financial consequences of the solution should also be thoroughly examined. Remote monitoring of pH, temperature, and turbidity was also implemented in another IoT-based aquaculture system [8]. Sensors in the system gather the information. The overall success rate for monitoring acid-base and water temperature in all implemented systems is 97.66%. A score of 1-9 indicates crystal-clear water, 10-24 moderate cloudiness, 25-49 cloudiness, and 50+ extreme cloudiness.

The study article presents three hypothetical models for the fishing industry's digitalization [9]. Using the detector networks, the WSN system models the energy several sensors consume. Data collected by wearable sensors for marine surveillance is analyzed temporally. The value of the WSN principle, as applied to the monitoring of ocean buoys with detectors, is evaluated in the context of a case study from the fishing business. The characteristics of the snow crab collection are assessed using time series data and scatterplots from a global ocean buoy perspective. This article discusses how the fishing industry might benefit from Internet of Things (IoT) technology by keeping tabs on topics like product authenticity and vendor track records. The proposed strategy has the potential to enhance supply chain management.

The research paper [10] examines the use of AI in aquaculture. Research was also conducted on the data, processes, and outcomes of DL (deep learning)-based smart fish farming. This study was conducted to further inform academics and industry professionals on applying DL in aquaculture to facilitate the deployment of smart fish farming systems and better understand their benefits. Salinity, dissolved oxygen, pH, and temperature can all be controlled by AI-based systems. The software for the multiparameter water quality meters is hosted on an application server. Innovative fish farming methods showed how the complexity of seafood production can be reduced by applying science and technology.

In Brazilian fish farms, stereo cameras can determine a tank's average weight of Nile tilapia. This weight estimation for fish is determined by its 3D length. Nevertheless, breadth is among the most correlated variables with fish weight. Consequently, the objective of the research study referenced in [11]is to enhance this estimation by using stereo cameras and examining the cloud point on the surface of the fish. This report provides preliminary results that catalyze further investigation due to their resemblance to the present methodology.

Genome editing, artificial intelligence, offshore farming, recirculating aquaculture systems, oral vaccination, blockchain for marketing, and the Internet of Things are all examples of cutting-edge technologies that could improve aquaculture's long-term viability and financial success. In [12] we get an overview of these innovative new technologies and how they might be applied to aquaculture to improve the industry's long-term viability and bottom line.

The outcomes observed in most of the studies discussed above highlight the potential of IR4.0 technologies, particularly IoT and AI, to confront the challenges associated with fish farming in confined spaces or pond water. In our proposed work, we presented a framework based on IR4.0 technologies that can be deployed in marine fish farms to tackle the challenges detailed in section II. To illustrate this, we have selected a real-time case study from Oman, which will be discussed in the subsequent section.

IV. CASE STUDY FROM OMAN

The World Bank classifies Oman as a developing country with a high-income economy. According to the United Nations Industrial Organization report, Oman is ranked as Laggard concerning advanced digital production technologies (ADP)[13]. Oman's geographical location supports Marine Aquaculture Production due to several factors, including a suitable marine environment with cultivable aquatic organisms, an investment-friendly environment, a legal and institutional framework for the fish farming sector, and a strategic location near significant export markets and world-class infrastructure. According to the plans developed in the Fish Wealth Implementation Program, its production is expected to reach 100,000 tons by 2023 [14]

As a developing economy, Oman faces challenges in adopting IR4.0 digital transformation. One of these critical challenges is the digital skill gap in the current and upcoming workforce. As per the recommendations of the World Economy Forum [15], this challenge can be eliminated by governments, businesses, and other stakeholders adopting specific strategies.

In the case of Oman, the fishery sector is moving towards privatization, an economic strategy aiming to create governmental companies managed by the Oman Investment Authority (OAI). The Fisheries Development of Oman (FDO) company, owned by the government, was founded to foster a sustainable commercial aquaculture and fishing sector in Oman. This endeavour results from a collaborative partnership between the Ministry of Agriculture and Fisheries Wealth and the Oman Investment Authority (OIA) [16]By way of illustration, Blue Waters Company is under FDO groups. Blue Water aimed to invest commercially and advance Oman's fin fish aquaculture industry. It is anticipated to trigger domestic and foreign private-sector investments in Oman's aquaculture industry, which spans the entire value chain. Primarily, they are investing in fish farming projects, modern processing, packing, and logistic facilities. One of the current projects is Marine Fin Fish Cage Farms, which aims to reach 7,000 tons annually [17].
There is plenty of research for development projects (R&D) in the aquaculture industry. We are exploring some specific challenges in this case study, illustrated below after the authors had a field visit to Blue Water.

In March 2023, the research team conducted a focused group discussion with three employees of the Blue Water Company during a formal visit to their Quriyat, Oman, premises. The debate centered on thoroughly understanding the infrastructure and systems employed in their offshore fish farms. The employees provided detailed explanations, and the conversation delved into the challenges faced by the company daily. Several challenges piqued the team's interest and showed promising potential for resolution through the application of cutting-edge technologies.

One challenge related to using an efficient mechanism for monitoring fish size is identifying the right time for harvesting. Another challenge is to find a way of watching the oxygen level for 24 hours/ seven days and get alarmed when the level goes beyond the acceptable levels for fish to grow. A third challenge is the feeding amount and time to ensure the fish get suitable care to grow and stay alive. Additionally, there should be a way to monitor the cage's movement to ensure they are not changing their places dramatically.
As per the challenges listed, it is observed that a system should be developed consisting of technologies related to IoT (Internet of Things), AI (Artificial Intelligence), and Data Science. Some commercial solutions might be off the shelf, but they need to be customized. It might have some features and meet the Omani marine environment's challenges. Still, it is designed to meet only some specifications and requirements in addition to the maintenance challenge and high prices. Therefore, enabling and supporting the national R&D framework will save costs and effort and enhance sustainability for the solutions articulated by national bodies, leading to self-sufficiency.
Therefore, this research proposes a framework to solve the challenges via IR4 technologies and enable triple helix collaboration [18]

V. FRAMEWORK (PROPOSED) FOR SOLVING ONE CHALLENGE USING IR4

Based on the literature review, one of the key findings from the case studies of different continents is that IR4.0 technologies have enormous potential to improve the financial status and economy of the respective countries.

From the statistics of Oman's economy, it has been observed that there is a need to invest wisely in non-oil activities. IR4 is based on the latest technology transformation per the current industrial wave. Therefore, there is an urgent demand to elevate Oman's level in adopting IR4 technologies as other countries embrace [19].

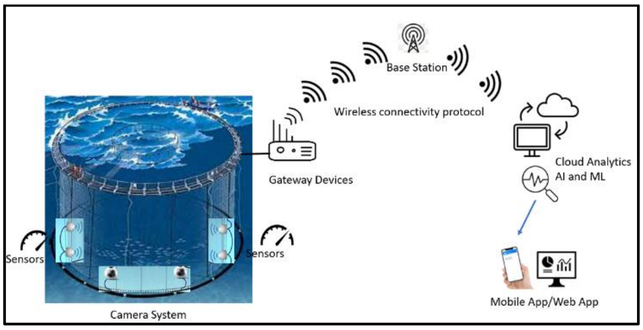

Figure 1: IoT framework to design a solution for the Oxygen Challenge

Upon assessing the challenges faced by Blue Water company, it becomes evident that addressing them will necessitate utilizing multiple Industry 4.0 technologies. For instance, IoT can effectively monitor oxygen levels using sensors such as a DO sensor or dissolved oxygen kit connected with a microcontroller for processing and sending the data to the app interface through wireless technology such as LORAWAN, ZigBee, etc. Tasks like monitoring fish size and cage movement require the synergy of 3D cameras, stereo camera systems, and computer vision techniques to estimate fish size. AI and machine learning algorithms can also estimate fish biomass based on feeding schedules and quantities and anticipate cage movements due to harsh climatic conditions. Figure 1 Shows an overall framework that can be used to address the Oxygen Level challenges. As a result, our framework seamlessly integrates these technologies into a unified system equipped to tackle all these challenges comprehensively. Furthermore, the framework's design allows for the future integration of additional technologies, such as blockchain for supply chain management and marketing, to expand its functionality.

One of the strategies adopted by the proposed framework is that the governments should develop an agile approach to initiate upskilling future workforce in IR4.0 digital skills in collaboration with business, non-profit, and education sectors. This strategy reflects the deployment of the triple-helix model.

This research will incorporate these essential strategies to develop an innovative R&D framework, as illustrated in Figure 2.

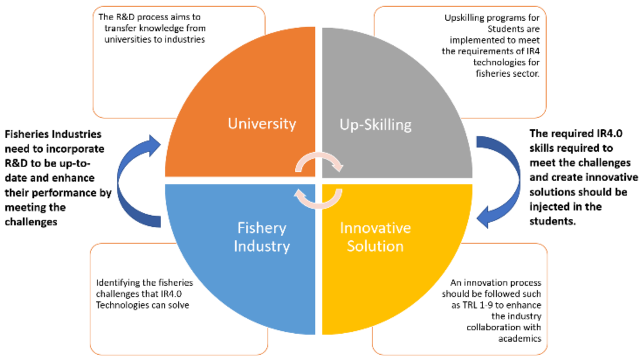

Figure 2 proposed upskilling framework.

The framework comprises four pillars: university, up-skilling, innovation solutions, and the fishing industry. This framework design is constructed based on the Technology Transfer concept [20]–[22], Technology Readiness Level (TRL)[23]–[25], Research for Development (R&D) approach [26]–[28], and Innovation Global Index (GII) [29], [30]. The collaboration between all those approaches and concepts is to enhance the economy based on knowledge.

Universities are considered knowledge factories. NASA initially used the TRL scale of 9 levels to identify the steps of transferring technology to the industry. Level-1 starts from university, and level-9 reaches the commercialization of industry. This process involves research to enhance development, which differs from traditional research to improve knowledge domains. The framework starts by identifying the skills required to solve challenges related to enhancing industry operations.

As per the framework, a collaboration between the Blue Water Company and the university will lead to designing an upskilling program. As a result of the successful implementation of this program, the students can devise innovative solutions for the challenges specified by the company using the identified IR.4 technologies. Currently, we have a program in progress where the students are involved to enhance their data science and platform development skills. The students who graduate from this program are more confident in working on projects related to real-time. The next stage is to collect a real dataset from Blue Water to apply data science mechanisms to visualize data from 2018, and the analysis will be based on designing solutions for the identified challenges, such as Oxygen Level and fish size measurement.

VI. Conclusion

The proposed framework addressed the challenges faced by the marine fish farm industry. Through upskilling programs, it provided an opportunity to enhance students' skills in IR4 technologies such as IoT, AI and machine learning, Blockchain, etc. Students can explore real-world problems and be part of the R&D to develop an innovative solution to build an intelligent fisheries industry.

This framework will be deployed in the future with the collaboration between Blue Water Company and the University of Technology and Applied Sciences. Since this is an agile framework, the results obtained from the repeated deployment of the framework will be analyzed and evaluated for further improvement, and integration of other IR4 technologies can be done accordingly to solve future challenges.

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