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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



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OF INTEREST TO THE FOLLOWING COMMITTEES:

HORIZONTAL FUNCTION(S):

ASPECTS CONCERNED:

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TITLE:

Internet of Things (IoT) - Smart onshore aquaculture - General and technical requirements

NOTE FROM TC/SC OFFICERS:

As per the WG 5 recommendation (2025-05-22), the current document on the OSD is circulated for the 2nd CD consultation.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

Internet of Things (IoT) - Smart onshore aquaculture - General and technical requirements

FOREWORD

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The text of this International Standard is based on the following documents:

Draft	Report on voting

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, JTC1 Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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- revised.

INTRODUCTION

Aquaculture is the “farming” (thus, also known as aquafarming) of both the cultivation of underwater plants, and the breeding, rearing and harvesting of fish, shellfish, and other underwater organisms in a controlled environment. The practice of aquaculture can both fulfil future food needs and sustain natural resources. [1]

Aquatic animal products (e.g., fish, shellfish, etc.) are important sources of high-quality protein for people's daily life, and have important nutritional and health values, along with farm animals, i.e., livestock. In addition to ocean and freshwater fishing, onshore aquaculture is the main way to provide the aquatic animal products. Outdoor fish ponds, open-air recirculating aquaculture systems, factory recirculating aquaculture systems, etc. are the facilities for aquaculture or aquafarming.

Aquaculture markets can be classified by rearing product types (i.e., equipment, chemicals, pharmaceuticals), by culture (i.e., fresh water, brackish water, marine water), by species (i.e., aquatic plants, aquatic animals), by production types (i.e., small scale, medium, large scale), and by region (i.e., North America, Europe, Asia Pacific, Latin America, Middle East & Africa).

The aquaculture global market is rapidly growing. In 2022, global aquaculture market is valued at US\$289.6 billion and is projected to reach a value of US\$421.2 billion by 2030 at a CAGR (Compound Annual Growth Rate) of 5.5 % over the forecast period 2023-2030 [2]. The global fish farming market size was valued at US\$268.90 billion in 2021, envisioned to reach US\$409.56 billion by 2030 growing at a CAGR of 5.4 % [3]. The rapidly growing aquaculture market will cause regulatory challenges, resulting in increased risk of the industry becoming unregulated, falling short of stakeholder expectations due to lack of aquaculture legislation and regulations, and negative impacts on the environment and societies do occur [4]. In order to mitigate or minimize these risks, aquaculture market needs well-designed legislation and proper regulations which comes with investment costs, benefits aquaculture industries, and creates a level playing field among business actors [4]. And proper and beneficial regulations must be based on well-established and industry-accepted standards [4].

Unlike other industrial sectors (e.g., medical, manufacturing, transportation, etc.), aquafarming industry has been lagging in adopting technologies (e.g., Internet of Things, sensor and control networks, sensing, data science and analytics, artificial intelligence, machine learning, etc.) for operations and management of aquaculture factories and systems. It is the intention of this document to spur and support the adoption of such technologies for secure and automated aquafarming operations and management by the well-established and industry-accepted standards. Furthermore, this standard focusing on transformation of the onshore farming of aquatic animals (e.g., fishes, shrimp, etc.) to become smart by applying the technologies available today and creating beneficial services for tomorrow by establishing the roadmap to smart aquaculture.

The current onshore aquafarming approaches lack standardized solutions and smart services for aquaculture operations and management (O&M ()) including, but are not limited to, water quality monitoring, environment/weather monitoring, facility and equipment monitoring, disease prevention, operational predictability, logistics and supply chain. As a result, the risks in achieving highly efficient aquaculture O&M () are high due to difficulties in standardizing aquatic products, inefficiency of manual management and production, deficiency in food safety and security in logistics and supply chain, unintended tardiness in marketing and sales, etc. Implementing a smart aquaculture system using the Internet of Things (IoT ()), data analytics, and other supporting technologies will provide the best mitigation for these risks associated with onshore aquaculture. The smart aquaculture system brings the following benefits:

- a) Accurate monitoring of water quality for 24X7, which includes dissolved oxygen, temperature, PH level, ammonia nitrogen, sub-salt, etc., to ensure maintaining healthy water quality to create an aquatic environment where aquatic animals can thrive;
- b) Intelligent monitoring of aquaculture system, equipment, and facilities, surrounding environment, and weather not only to ensure normal and stable operations but also to adapt

any changes to them and water quality in a timely manner avoiding any damages to physical assets and aquatic animals;

- c) Realization of an intelligent management of daily feeding, maintaining an optimal nutrient level, improving feed utilization rate and feed record keeping;
- d) Behaviour monitoring of aquatic animals, preventing large-scale outbreaks of diseases in advance and reducing mortality;
- e) Seamless supply chain and expedited logistics beginning from the quality and safety inspection of aquatic products to the delivery to customers, reducing the stress loss in the transportation process and guaranteeing the food safety;
- f) Continuous improvement of the standardized aquaculture operations and management process through artificial intelligence, machine learning, big data analytics, and other emerging technologies.

This general requirements for the smart onshore aquaculture system are the first step to address and achieve:

Reference or common system architecture for smart onshore aquaculture systems to promote the adaptation of [IoT](#) () enabling smart services to aquaculture industry and business;

- g) Interoperability among smart aquaculture devices and equipment from different manufacturers by standardized interfaces;
- h) Accurate analytics and data mining starting from data acquisition, data formation via formatting standards, error-free data transmission, data processing and storage;
- i) Intelligent management and control for aquaculture operations and processes supported by a large number of smart applications and services.

Aquaculture includes both the cultivation of underwater plants, and the breeding, rearing and harvesting of underwater fish, shellfish and other living organisms. The practice of aquaculture can both fulfil future food needs and sustain natural resources. Aquaponics is a combination of fish and plant production and hydroponics (growing plants without soil). [\[1\]](#)

This document focuses on the aquaculture of fish and other underwater living animals or organisms mainly due to the market size of fish farming is so much greater than underwater plant farming as shown in the earlier paragraph in this Introduction section. Yet, the fish aquafarming reference architecture, requirements, and specifications for rearing environment and systems can readily adopted for underwater plant farming.

1 Scope

This document establishes an end-to-end system reference architecture (RA ()) for Internet of Thing (IoT ())-based smart onshore aquaculture (SONA ()) and specifies general requirements and technical specifications for the smart onshore aquaculture systems and their operations and management.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1

virtual actor

digital entity that performs an *a posteriori* decision-making process based on empirical evidence or outcomes via analyses of the data collected, , and that executes virtual and/or physical actions by linking decisions to corresponding actions within an operational or management system

3.2

user

person who uses or operates a digital platform, virtual or physical device to monitor and control an operational system, to provide service, or to receive service through a type of interface mechanism

4 Symbols and abbreviated terms

ADC	analogue-to-digital converter
AEO	approved external organization or organizations
AI/ML	artificial intelligence / machine learning
API	application programming interface
ASD	application and service domain
CCTV	closed-circuit television
DAS	data acquisition system
DERs	distributed energy resources
DTw	digital twin
EOU	external organizational user or users
ExD	external domain
ExU	user or users in the ExD ()
GUI	graphical user interface
HMI	human-machine interface

HW	hardware
IF	interface
IF-RAS	indoor factory-based recirculating aquaculture system
IoT	Internet of Things
O&M	operations and management
OF-RAS	outdoor facility-based recirculating aquaculture system
OMD	operations and management domain
OM-PAS	outdoor manmade pond aquaculture system
ON-PAS	outdoor natural pond aquaculture system
PED	physical entity domain
RAID	resource access and interchange domain
RA	reference architecture
RAS	recirculating aquaculture system
RFID	radio-frequency identification
SA	situational awareness
SCADA	supervisory control and data acquisition
SCD	sensing and controlling domain
SONA	smart onshore aquaculture
SONA-RA	smart onshore aquaculture reference architecture
SOFA	smart offshore aquaculture
SSL/TLS	secure socket layer and transport layer security
SW	software
UD	user domain
UE	user equipment
UI	user interface

5 Smart onshore aquaculture overview and system reference architecture

5.1 Overview

An end-to-end high-level system reference architecture ([RA \(\)](#)) for smart onshore aquaculture ([SONA \(\)](#)) is provided with its entirety from breeding, releasing fries to rearing environment (e.g., onshore or land-based aquaculture systems), harvesting, by-product recycling and productization processing, marketing and sales, shipping logistics, supply chain, to end-users and consumers.

The onshore aquaculture systems include:

- Outdoor natural pond aquaculture system ([ON-PAS \(\)](#)),
- Outdoor manmade pond aquaculture system ([OM-PAS \(\)](#)),
- Outdoor facility-based recirculating aquaculture system ([OF-RAS \(\)](#)), and
- Indoor factory-based recirculating aquaculture system ([IF \(\)-RAS \(\)](#)).

This smart onshore aquaculture reference architecture ([SONA \(\)-RA \(\)](#)), shown in [Figure 1](#), can be applied and adapted not only by the various types of onshore aquaculture systems, but also by smart offshore aquaculture ([SOFA \(\)](#)) with proper modifications.

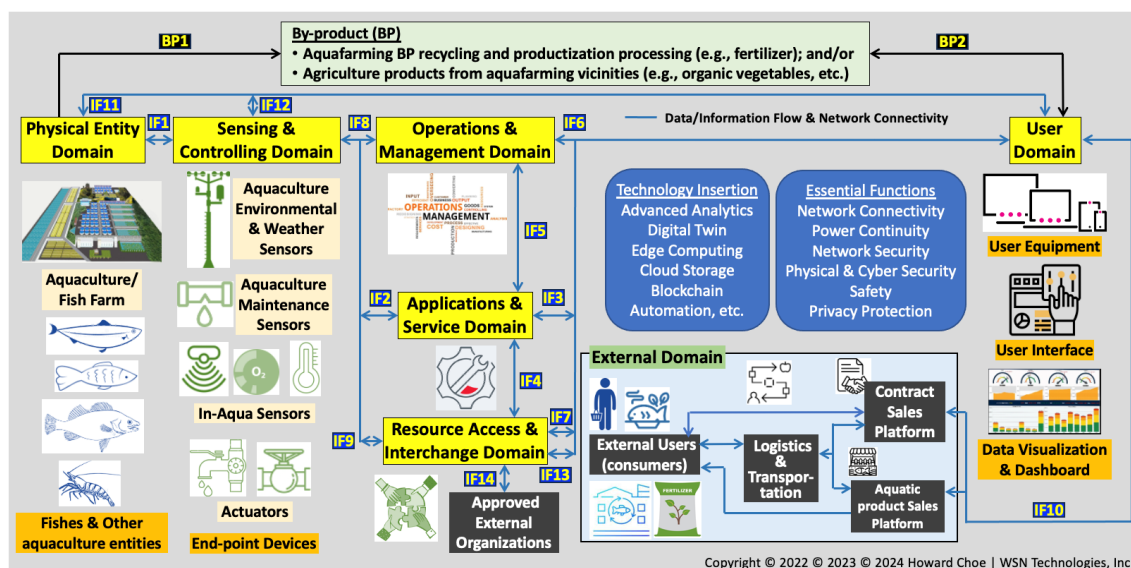


Figure 1 – High-level system reference architecture for smart onshore aquaculture [4].

The **SONA ()-RA ()** is described by the six domains specified in **ISO/IEC 30141:2024 [5]** **ISO/IEC 30141:2024** with the addition of external domain. The six domains are:

- User domain (**UD ()**)
- Physical entity domain (**PED ()**)
- Sensing & controlling domain (**SCD ()**)
- Applications & service domain (**ASD ()**)
- Operations & management domain (**OMD ()**)
- Resource access & interchange domain (**RAID ()**)

In addition to the six domains, one domain is added for **SOFA ()-RA ()**, that is:

- External Domain (**ExD ()**)

The external domain has external users (contract buyers, logistics companies, suppliers, end-users, consumers, etc.) and platforms for marketing & sales, supply chain (e.g., shipping, transportation), etc. It is essential to show the end-to-end aquaculture from technology and business perspectives to benefit the stakeholders of onshore aquaculture businesses.

In addition to the **SONA ()-RA ()**, general and technical requirements associated with **SONA ()** are specified in this document that can transform the traditional aquaculture and its business to smart and intelligent operations and management (**O&M ()**). Such transformation will impact:

- development of smart aquaculture platform, e.g., fish farming platform;
- wired and wireless network composition and configuration;
- network connectivity
- network cybersecurity;
- facility physical security;
- data and information privacy and protection;
- food security;
- safety (for both human operators and aqua products, e.g., fishes, etc.)
- **O&M ()** control and automation;
- effective and increased quality control;

- power continuity;
- usage of alternative (e.g. centralized or hybrid) or distributed energy resources (DERs ());
- energy efficiency over a lifecycle (i.e., a fish farming period of a species); and
- development of aquaculture/farm's surrounding real estate.

This document addresses and encourages the insertion of advanced technology for aquaculture end-to-end O&M (). Although specific requirements or specifications for these advanced technologies are not addressed in this document, their potential applicability in aquaculture are discussed to benefit the stakeholders. These advanced technologies include, but are not limited to:

- artificial intelligence / machine learning (AI/ML ());
- advanced data analytics;
- digital twin (DTw ());
- edge computing;
- cloud storage;
- blockchain; and
- predictive maintenance

5.2 End-to-end smart onshore aquaculture reference architecture

The end-to-end smart onshore aquaculture reference architecture (SONA ()-RA ()), as shown in Figure 1 can be adopted or modified and implemented for the aquaculture O&M () of ON-PAS (), OM-PAS (), OF-RAS (), and IF ()-RAS (). The SONA ()-RA () integrates numerous technologies, especially, Internet of Things (IoT ()) for aquaculture O&M () automation. The SONA ()-RA () shall provide aquafarm¹ situation awareness (SA ()) by sensing, analysing, monitoring, and in some situations controlling networked entities via user equipment in the user domain by the O&M () users for full automation of aquafarm O&M (). However, for the SONA ()-RA () for certain type of aquafarms (e.g., small aquafarm business by a single family, etc.), the full O&M () automation may not be necessary or needed.

Depending on the aquafarm's operation scale, the SA () monitoring dashboard should support the O&M ()SA () reporting via devices such as smartphone, tablet, desk or laptop computer. These devices are user equipment (UE ()) which shall provide user interface (UI ()) along with the SA () monitoring dashboard. An integrated unit consists of UE (), UI (), SA () monitoring dashboard, and O&M () supporting software (SW ()) is a human-machine interface (HMI ()). Through the HMI (), the users (i.e., human operators and/or managers) shall receive warning and notification messages about aquafarm conditions. These messages should remain on the dashboard until resolved. Authorized O&M () users shall be able to resolve the messages requiring an action or actions through the UI (). Certain messages are notifications of the actions taken by automation, which is called a resolution by a virtual actor. The SA () monitoring dashboard and UI () together will provide monitoring and controlling capabilities similar to a supervisory control and data acquisition (SCADA ()) system for aquafarming.

The SONA ()-RA () in Figure 1 provides aquaculture products' sales through contracts and on-line sales platform, logistics and supply chain to consumers (e.g., individuals, families) and end-users (e.g., markets, restaurants). Marketing & sales domain and supply-chain domain inclusive of transportation are described along with the six (6) domains represented in the SONA ()-RA ().

¹ For terminology convenience, "aquafarm" collectively represents ON-PAS (), OM-PAS (), OF-RAS (), and IF ()-RAS () aquafarms.

5.3 Interface description

Interfaces of IoT ()-based SONA system is shown in Figure 1, and the interface descriptions in the perspective of information flow are described in Table 1. All interfaces in aquaculture, as outlined in Table 1, must implement secure data and information transmission protocols, as they involve the exchange of operationally important and, in some cases, critical data, including confidential and/or private information related to external customers. In particular, interfaces UD-SCD (IF12 in Table 1) and SCD-OMD (IF8 in Table 1) represent critical cyberattack surfaces and must be protected against cyber threats. Therefore, secure transmission mechanisms shall be implemented for IF8 and IF12.

Table 1 – High-level interface description between Domain 1 (D1) and Domain 2 (D2) in the SONA ()-RA (), with interface # (IF#) in Figure 1.

D1	D2	IF#	Interface description
UD ()	PED ()	IF11	- D1 to D2: Automated or manual command & control for reconfiguring sensors and actuators, including firmware updates, and also recalibration of sensors and actuators at a pre-set time interval to prevent sensors and actuators from drifting. - D2 to D1: Direct communication from the PED to the UD, bypassing the SCD, is permitted under the following situations: (1) when the UD initiates direct requests for PED devices' (e.g., data or status information of sensors and actuators; and (2) in emergency situation, where predefined threshold conditions in sensors or actuators are met, triggering an automatic emergency response or command execution.t
UD ()	SCD ()	IF12	- D1 to D2: Sensors and controller SW () and API () configurations/updates, aquafarming environment monitoring configuration, automated/manual command & control via the SCD (), etc. - D2 to D1: Information about the aquafarm organism and environment, status of all actuators that control the systems in aquaculture facility, warning or report of any abnormality detected or identified, sensor or actuator not responding to commands sent from the UD (), sensor and actuator status, e.g., battery replacement, sensor or actuator malfunction, etc., regular interval (e.g., daily) pinging to sensors and actuators for their responses for their condition monitoring, etc.
UD ()	OMD ()	IF6	- D1 to D2: System operation scheduling or reconfiguration, system maintenance scheduling, workforce assignment and scheduling, etc. - D2 to D1: Operational status of aquafarm systems and devices, predictive/condition-based and scheduled maintenance alarms, abnormal operation warnings, notification for automated emergency command & control for aquafarm systems.
UD ()	ASD ()	IF3	- D1 to D2: Application & service SW () and API () configurations/updates, new application or service introduction, Invocation of applications or services. - D2 to D1: Information and usage of application and services accessed by the entities in the OMD (), information and usage of application and services in the entities and accessed by external organizations in the RAID (), logging of data used and produced by applications and services.
UD ()	RAID ()	IF7	- D1 to D2: Responses (decisions, approvals, etc.) to AEO () requests, financial transactions, supplier management, issuance of contracts or invoices, outgoing payments, etc. - D2 to D1: AEO () requests for various types of data, incoming invoices, incoming payments, etc.
UD ()	ExD ()	IF10	- D1 to D2: Information/data (aquatic products and by-products, pricing information, delivery options, etc.) to the contract sales platform and the aquatic product sales platform, approved logistics & transportation organizations accessed by the platforms. - D2 to D1: Platform sales information, aquatic items sold (for inventory control - data sent to the O&M ()), total sales amount, customer information (geolocation, etc.), etc.
PED ()	SCD ()	IF1	- D1 to D2: Data/information from all sensors, actuators, ID readers (RFID (), QR & barcode), controllers in aquaculture systems, all manual collection data (via entry to handheld devices), external data/information (e.g., weather forecast, etc.), etc. - D2 to D1: Periodic (e.g., per day) pinging signals to check sensors and actuators status, sensing and control command & control (automated and from the UD ()), sensor and controller parameter (re)setting and reconfiguration, firmware updates, etc.
SCD ()	OMD ()	IF8	D1 to D2: Information generated by processing (e.g., aggregation, fusion, integration, trending, predictions, etc.) sensors and controllers (actuators) data, pre-warning and warnings, sensor and actuator status, etc.

D1	D2	IF#	Interface description
			D2 to D1: Command & control for reconfiguring monitoring systems, on-demand real-time data access, aquafarming environment monitoring configuration, automated/manual command & control via the SCD (), etc.
SCD ()	ASD ()	IF2	- D1 to D2: Information generated by processing (e.g., aggregation, fusion, integration, trending, predictions, etc.) sensors and controllers (actuators) data, pre-warning and warnings, sensor and actuator status, etc. - D2 to D1: Request to obtain certain SCD () data to perform application or provide service requests from UD (), OMD (), or RAID () with data access authorization and privilege (e.g., access levels) per each request.
SCD ()	RAID ()	IF9	- D1 to D2: Data that satisfy an authorization and access level from the request of AEO () via the RAID (). - D2 to D1: AEO ()'s data/information requests entered in the RAID ()'s access-controlled user interface.
OMD ()	ASD ()	IF5	- D1 to D2: O&M () related application and service requests. - D2 to D1: Notification of O&M () requests completion with associated data logging or incompleteness of the requests with the reason or issues why it was not completed.
OMD ()	RAID ()	IF13	- D1 to D2: Accept and reject of AEO () request from the RAID () and reasons if rejected. O&M () related data per AEO ()'s request through the RAID (). - D2 to D1: AEO ()'s requests of O&M () data with authorization and data access level.
ASD ()	RAID ()	IF4	- D1 to D2: Execution of application or service requested by AEOs through the RAID (). Data generated or transaction completed notification (e.g., acknowledgement, receipts, invoices, etc.). - D2 to D1: Application or service requests by AEOs through the RAID () with AEO () authorization and access levels for ASD ()'s applications and services.
RAID ()	AEO ()	IF14	- D1 to D2: Various types of data, information, financial transactions, etc. from UD (), SCD (), OMD (), or ASD () per the nature of AEO () requests when AEO ()'s authorization and access privilege are verified. - D2 to D1: Various types of AEO () requests entered through the RAID ()'s AEO () user interface.
PED	BP	BP1	- D1 to D2: This interface is only present when aquaculture by-product processing is in operation. Physical by-products generated from the PED – such as uneaten feed and fish manure – are transported to the by-product processing facility, where they are converted into organic fertilizer. The resulting fertilizers may either be sold to external users in the ExD or utilized for cultivating crops (e.g., vegetables) in areas surrounding the aquafarm. - D2 to D1: This interface is not required.
BP	UD	BP2	- D1 to D2: This interface is only required when aquaculture by-product processing is implemented. For by-products owned by the aquaculture organization, production data and relevant information are transmitted to the UD to enable listing of the products for sale on the Aquatic Product Sales platform in the ExD. - D2 to D1: Sales and delivery information is communicated to personnel in the BP.

5.4 SONA ()-RA () domain and entity description

5.4.1 User domain

In aquafarming business, largely two types of users exist: (1) internal users; and (2) external users. The internal users are the users who are involved in aquafarming, e.g., the employees of aquafarms such as operations and management personnel. The external users are the aquafarm suppliers, shipping & transportation companies, contract buyers (e.g., super markets, restaurants, etc.), and consumers (e.g., individual person, families, etc.).

5.4.1.1 Internal users

The user domain (**UD ()**) shall have the **O&M ()** personnel who are the human users in the **UD ()**. The users interact with aquafarms using an **HMI ()**. Depending on user's role, responsibility and authority, the users shall have different levels of accessibility in the **HMI ()** to monitor and control the aquafarms.

In addition to the human users, digital actors can reside in the [UD \(\)](#). A virtual actor is a digital entity which is an element in system automation. The virtual actor shall send a control command or a sequence of control commands without intervention of the users, i.e., the [O&M \(\)](#) personnel, based on monitoring and automated [SA \(\)](#) analysis outcomes.

In the [UD \(\)](#), to enable the users to interact with the aquafarm systems, there should be terminals or devices that provide interfaces. These devices can be smartphones, tablets, and desk or laptop computers. For the operations of a large number of aquafarms, a system similar to [SCADA \(\)](#) can be more appropriate than the handheld devices or computers. Includes terminals or devices, or the APP installed in the smart phone or smart digital devices, and software or the web page loaded on the computer.

The software ([SW \(\)](#)) that provides the [HMI \(\)](#) functions on these devices or systems can take a form of API or graphical user interface ([GUI \(\)](#)). The API and [GUI \(\)](#) need to be intuitive and easy to operate while they should provide the users a comprehensive status of the aquafarms under monitoring. They also need to provide access to a toolset for analysis if/when analytical functions (e.g., historical data trending, water quality/environment condition monitoring, system and device health monitoring, preventive maintenance, etc.) are implemented and a toolset for aqua product quality and quantity evaluation (e.g., fish size and mass, fish count, etc.).

The internal users should maintain and updates the applications, services, and platforms used by the external users. Depending on business decisions, the external user applications, services, and platforms can be developed, maintained, and updated by a third-party company.

The external domain shall not have access to the [UD \(\)](#) and [UD \(\)](#)'s entities (e.g., user equipment and user interface in [UD \(\)](#)). The network connecting the [UD \(\)](#) and the external domain is unilateral from the [UD \(\)](#) to the external domain for cybersecurity protection of the aquafarm along with other cybersecurity protection measures.

5.4.1.2 External users and external organizational users

From the reference architecture perspectives, external users and external organizational users do not belong to the [UD \(\)](#). As they are categorized as "users," these external users shown in this section for information only. For the descriptions of the external user and external organizational users, refer to [5.4.7.1](#).

The descriptions of the entities in [UD \(\)](#) are provided in [Table 2](#)

Table 2 – Description of entities in the user domain ([UD \(\)](#)).

Entity	Description
(Internal) Users	Aquaculture business' employees authorized to manage, operate, and maintain aquaculture/farming facilities, systems, platforms, etc. These users are responsible for safe, reliable, secure (both physical and cyber), reporting, etc., to run the aquaculture 24X7. The manager users are responsible for aquatic product sales and price determination, supplier management,
User equipment (UE ())	UE () includes desktop computers, laptops, tablets, smartphones that are used by the users to operate and manage the aquaculture/farming facilities, systems, and any other activities related to the aquaculture business.
User interface (UI ())	UI () are graphical user interfaces of SW () tools and utilities and app including, but are not limited to, visualization tools, analytical and statistical tools, cybersecurity tools, predictive/condition monitoring tools, system historical trending tools, data storage and archiving tools, reporting tools, graphical presentation tools, etc.
Dashboard & visualization	Dashboard presents the overall summary of the aquaculture operation status visually displaying selected parameters by the operation and business management. All critical systems' operational status is shown and any warning is also indicated in ways to alert the operators in addition to the warning alerts to the UEs.
External users & external organizational users	Refer to 5.4.7.1 .

5.4.2 Physical entity domain

The physical entity domain (**PED ()**) consists of physical entities that are physical objects being sensed, monitored, and controlled by various types of sensors. Depending on the onshore aquaculture/aquafarming system models, i.e., **ON-PAS ()**, **OM-PAS ()**, **OF-RAS ()**, and **IF ()-RAS ()**, the physical entities involved can vary. Yet, the common physical objects are, for example, aquatic products (e.g., fish, plants, etc.), aquafarm water, aquatic feeds, various contents in the water (oxygen, nutrients, medicine, harmful contents, etc.), microorganisms, water and air, and other controllable indoor or outdoor climate elements. Some of these objects are controlled by their corresponding actuators to optimize the aquafarm environment for aquatic products.

Some of the aforementioned objects and the interrelationships between objects can be measured by specific sensors in the Sensing and Controlling Domain (**SCD ()**), such as dissolved oxygen, pH, ammonia nitrogen, salinity, and temperature of aquaculture water.

The **PED ()** also includes all types of controlling devices used in aquafarming such as valves, pumps, feeder, aerator, etc. The actuators that control these devices architecturally belong to the **SCD ()**. In addition to the sensors, tags (e.g., barcode, QR code, and radio-frequency identification (**RFID ()**)) can be attached on certain physical objects, such as aquatic feed, medicine, chemicals, shipping containers, and other supplies for aquafarm operations, for inventory control and product shipping management. Tag readers should be used to read the tags. The tag readers are entities in the **SCD ()**, not in the **PED ()**.

Network (either wired or wireless, or combined) connectivity between the users in **UD ()** and the objects in the **PED ()** shall be required for the data/information about the aquaculture systems, which realizes continuous monitoring and optimization of the aquaculture system management and operations. In addition to the above methods, some physical objects in the **PED ()** can also be attached with tags for identification, used for inventory control and product transportation management.

The **PED ()**'s entities in the aquaculture/aquafarming system models include aquaculture products (can be further divided according to aqua-product category and cultivation stage), aquaculture water, aquaculture effluent, water substances, water organisms, microorganisms in water, aquaculture facilities, aquaculture equipment, feed, pharmaceuticals/medicine for aqua-products; electric power facilities, water temperature control facilities, and surrounding environment of the aquaculture system. An additional **PED ()** entity is the logistics system which includes sorting facilities, logistics vehicles, and storage tanks.

The descriptions of the entities in the **PED ()** are provided in [Table 3](#).

Table 3 – Description of entities in the physical entity domain (PED ()**).**

Category	Entity	Description
Aquaculture systems	Aquaculture products	Products produced during aquaculture processes, including fish, shrimp, shellfish, plants, etc., at different species and stages of cultivation.
	Aquaculture water	Water used in aquaculture/farming such as water in aquaculture pond, water for pond filling and in circulation systems, and supplementary water sources.
	Aquaculture effluents	Waste water generated during the aquaculture process, which is treated before being discharged into the environment or reused.
	Aquaculture substances	Important chemical substances present in aquaculture water, such as dissolved oxygen, pH, ammonia nitrogen, salinity, etc.
	Aquatic organisms	Biological organisms present in aquaculture water, including fish, shrimp, shellfish, etc.
	Aquatic microorganisms	Microbial communities present in aquaculture water, including bacteria, algae, etc.