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

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

Draft	Report on voting
JTC1-SC41/568/CDV	JTC1-SC41/625/RVC

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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INTRODUCTION

Aquaculture (also known as aquafarming) is 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 (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 aquatic animal products. Outdoor fish ponds, open-air recirculating aquaculture systems, factory recirculating aquaculture systems, etc. are the facilities for aquaculture.

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 scale, large scale), and by region (i.e. North America, Europe, Asia Pacific, Latin America, Middle East and Africa).

The aquaculture global market is rapidly growing. In 2022, global aquaculture market was 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 to 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 because of lack of aquaculture legislation and regulations, and
– negative impacts on the environment and society [4].

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In order to mitigate or minimize these risks, the aquaculture market needs well-designed legislation and proper regulations – which come with investment costs – to benefit aquaculture industries and create a level playing field among business actors [4]. And proper and beneficial regulations must be based on well-established and industry-accepted standards [4].

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Unlike other industrial sectors (medical, manufacturing, transportation, etc.), the aquaculture industry has been lagging in adopting technologies (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 document focuses on the 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 aquaculture approaches lack standardized solutions and smart services for aquaculture operations and management (O&M) including, but not limited to, water quality monitoring, environment and 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 because of 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, 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 and continuous monitoring of water quality, which includes dissolved oxygen, temperature, pH level, ammonia, nitrogen, salinity, etc., to ensure maintaining healthy water quality to create an aquatic environment where aquatic animals can thrive;
b) intelligent monitoring of the 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 damage to physical assets and aquatic animals;

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c) realization of an intelligent management of daily feeding, maintaining an optimal nutrient level, improving feed utilization rate and feed recordkeeping;

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.

The following general characteristics for the smart onshore aquaculture system are the first to address and achieve:

g) reference or common system architecture for smart onshore aquaculture systems to promote the adaptation of IoT enabling smart services to aquaculture industry and business;

h) interoperability among smart aquaculture devices and equipment from different manufacturers by standardized interfaces;

i) accurate analytics and data mining starting from data acquisition, data formation via formatting standards, error-free data transmission, data processing and storage;

j) 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]

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This document focuses on the aquaculture of fish and other underwater living animals or organisms mainly because the market size of fish farming is so much greater than that of underwater plant farming, as indicated above in this Introduction. Yet, the fish aquaculture reference architecture and requirements for rearing environment and systems can readily be adopted for underwater plant farming.

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1 Scope

This document establishes an end-to-end system reference architecture (RA) for Internet of Things (IoT)-based smart onshore aquaculture (SONA) and specifies general requirements and technical requirements 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
aquafarm
aquaculture farm that collectively represents outdoor aquaculture systems, outdoor artificial pond aquaculture systems, outdoor facility-based recirculating aquaculture systems, and indoor facility-based recirculating aquaculture systems

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3.2
virtual actor
VA
digital entity that performs an *a posteriori* decision-making process based on empirical evidence or outcomes via analyses of the collected data, and that executes virtual or physical actions or both by linking decisions to corresponding actions within an operational or management system

3.3
user
person who operates a digital platform or accesses a virtual or physical device to monitor and control a system, to provide a service, or to receive a service via an interface

3.4
external user
ExU
user in the external domain

4 Abbreviated terms

AEO	approved external organization
AI/ML	artificial intelligence and machine learning
API	application programming interface
ASD	application and service domain
BP	by-product
DAS	data acquisition system
EOU	external organizational user
ExD	external domain
ExU	external user

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GDPR	General Data Protection Regulation
HIPAA	Health Insurance Portability and Accountability Act
HMI	human–machine interface
IF	interface
IF-RAS	indoor factory-based recirculating aquaculture system
IoT	Internet of Things
NTU	nephelometric turbidity unit
O&M	operations and management
OF-RAS	outdoor facility-based recirculating aquaculture system
OM-PAS	outdoor artificial pond aquaculture system
OMD	operations and management domain
ON-PAS	outdoor natural pond aquaculture system
PED	physical entity domain
RA	reference architecture
RAID	resource access and interchange domain
RAS	recirculating aquaculture system
RFID	radio-frequency identification
SA	situational awareness
SCADA	supervisory control and data acquisition
SCD	sensing and controlling domain
SmAq	smart aquaculture
SONA	smart onshore aquaculture
SONA-RA	smart onshore aquaculture reference architecture
SW	software
TLS	transport layer security
UD	user domain
UE	user equipment
UI	user interface

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5 Smart onshore aquaculture overview and system reference architecture

5.1 Overview

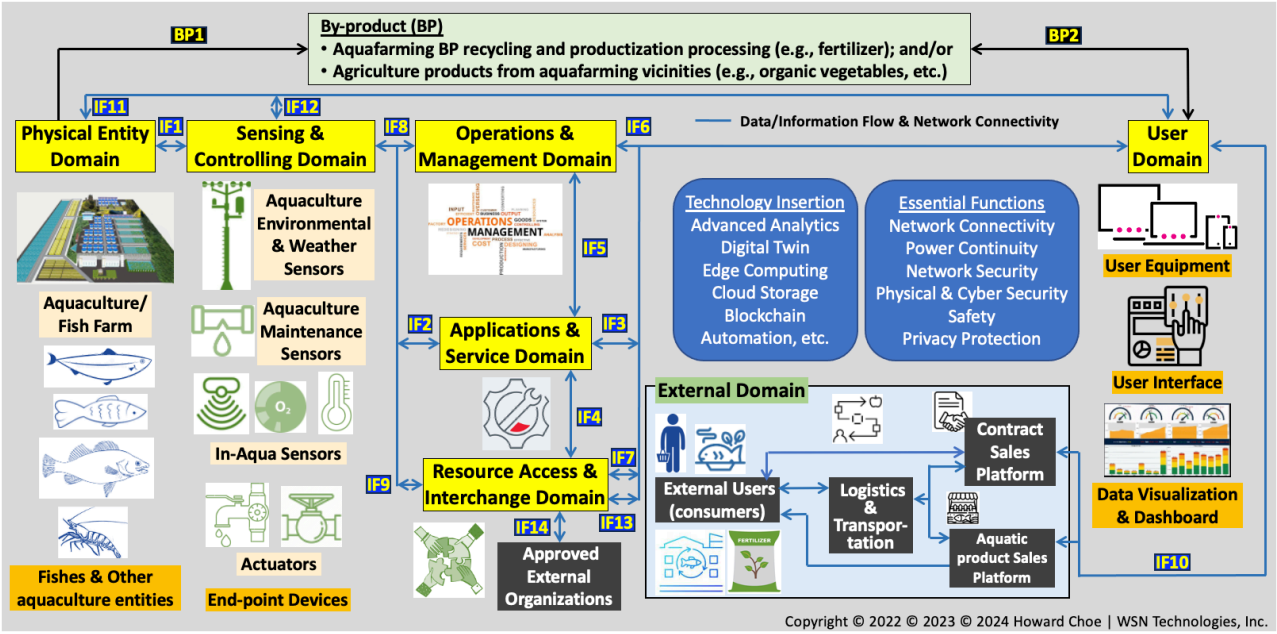
This document specifies an end-to-end high-level system reference architecture (RA) for smart onshore aquaculture (SONA) in its entirety – from breeding, releasing fries to rearing environment (e.g. onshore or land-based aquaculture systems), harvesting, by-product recycling and productization processing, marketing and sales, shipping logistics, supply chain, to end-users and consumers.

Broadly, onshore aquaculture systems can be categorized into four types:

– outdoor natural pond aquaculture system (ON-PAS);
– outdoor artificial pond aquaculture system (OM-PAS);
– outdoor facility-based recirculating aquaculture system (OF-RAS);
– 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 with appropriate modifications.

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Figure 1 – High-level system reference architecture for smart onshore aquaculture

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The SONA-RA is described by the following six domains specified in ISO/IEC 30141:2024 [5] :

– user domain (UD);
– physical entity domain (PED);
– sensing and controlling domain (SCD);
– applications and service domain (ASD);
– operations and management domain (OMD);
– resource access and interchange domain (RAID).

In addition to the six domains, one domain is added for SONA-RA:

– external domain (ExD).

The ExD has external users (contract buyers, logistics companies, suppliers, end-users, consumers, etc.) and platforms for marketing and 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 (SmAq) 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;

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– safety (for both human operators and aquaculture products, e.g. fish);
– O&M control and automation;
– effective and increased quality control;
– power continuity;
– usage of alternative (e.g. centralized or hybrid) or distributed energy resources;
– energy efficiency over a lifecycle (i.e. a fish farming period of a species);
– development of aquafarm'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 is discussed to benefit the stakeholders. These advanced technologies include, but are not limited to,

– artificial intelligence and machine learning (AI/ML),
– advanced data analytics,
– digital twin,
– edge computing,
– cloud storage,
– blockchain, and
– predictive maintenance.

5.2 End-to-end smart onshore aquaculture reference architecture

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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 aquafarm 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 a certain type of aquafarm (e.g. small aquafarm business run by a single family), the full O&M automation is possibly not needed.

Depending on the aquafarm's operation scale, the SA monitoring dashboard should support the O&M's SA reporting via devices such as smartphone, tablet, desktop computer or laptop computer. These devices are user equipment (UE) which shall provide a 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 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, and then the authorized user can clear the messages. The messages and the corresponding resolution taken shall be recorded in the O&M event log book. 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 aquaculture.

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

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5.3 Interface description

Interfaces of an IoT-based SONA system are shown in Figure 1, and the interface descriptions from the perspective of information flow are described in Table 1. All interfaces in aquaculture, as outlined in Table 1, shall implement secure data and information transmission protocols, as they involve the exchange of operationally important and, in some cases, critical data, including confidential and 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 shall 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 number (IF#) in Figure 1

D1	D2	IF#	Interface description
UD	PED	IF11	– D1 to D2: Automated or manual command and 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' 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.
UD	SCD	IF12	– D1 to D2: Sensors and controller SW and API configurations and updates, aquaculture environment monitoring configuration, automated or manual command and control via the SCD, etc. – D2 to D1: Information about the aquafarm organism and environment (i.e. all sensor data, locally processed sensor data; refer to Annex A for aquaculture sensor types and their parameters), status of all actuators that control the systems in the 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 (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 and condition-based and scheduled maintenance alarms, abnormal operation warnings, notification for automated emergency command and control for aquafarm systems.
UD	ASD	IF3	– D1 to D2: Application and service SW and API configurations and 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 and data (aquatic products and by-products, pricing information, delivery options, etc.) to the contract sales platform and the aquatic product sales platform, approved logistics and 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 (e.g. geolocation), etc. Because of the presence of potentially sensitive customer data within the sales information (e.g. credit card details, bank account information, email addresses), the sales information shall not be transmitted back to external users (ExUs), in order to ensure data security and privacy. Additionally, the sales data can be considered proprietary information of the aquaculture organization. Therefore, the sales information shall remain under the control of the organization and shall not be made accessible to ExUs. Furthermore, ExUs shall not have access to UD assets, such as UE and UI.
PED	SCD	IF1	– D1 to D2: Data and information from all sensors, actuators, ID readers (RFID, QR and barcode), controllers in aquaculture systems, all manual collection data (via entry to handheld devices), external data and information (e.g. weather forecast), etc. – D2 to D1: Periodic (e.g. per day) pinging signals to check sensors and actuators status, sensing and control command and control (automated and from the UD), sensor and controller parameter (re)setting and reconfiguration, firmware updates, etc.

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D1	D2	IF#	Interface description
SCD	OMD	IF8	– D1 to D2: Information generated by processing (aggregation, fusion, integration, trending, predictions, etc.) sensors and controllers (actuators) data, pre-warning and warnings, sensor and actuator status, etc. – D2 to D1: Command and control for reconfiguring monitoring systems, on-demand real-time data access, aquaculture environment monitoring configuration, automated or manual command and control via the SCD, etc.
SCD	ASD	IF2	– D1 to D2: Information generated by processing (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) for 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 and 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 non-completion 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 for each 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 (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 can either be sold to external users 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.

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5.4 SONA-RA domain and entity description

5.4.1 User domain

5.4.1.1 General

In aquaculture business, largely two types of user exist: internal and external. Internal users are the users who are involved in aquaculture, e.g. the employees of aquafarms such as operations and management personnel. External users are the aquafarm suppliers, shipping and transportation companies, contract buyers (supermarkets, restaurants, etc.), and consumers (individuals, families, etc.).

5.4.1.2 Internal users

The user domain (UD) shall include 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 access levels in the HMI to monitor and control the aquafarms.

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In addition to the human users, digital actors can reside in the UD. A VA is a digital entity which is an element in system automation. The VA 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 desktop 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. It includes terminals or devices, or the application installed in the smartphone or smart digital device, and software or the web page loaded on the computer.

The SW that provides the HMI functions on these devices or systems can take the form of an API or a graphical user interface. It is important that the API and graphical user interface are intuitive and easy to operate while they should provide the users with a comprehensive status of the aquafarms under monitoring. It is important that they also provide access to a toolset for analysis when analytical functions (historical data trending, water quality and environment condition monitoring, system and device health monitoring, preventive maintenance, etc.) are implemented and a toolset for aquaculture product quality and quantity evaluation (fish size and mass, fish count, etc.).

The internal users should maintain and update 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 ExD 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 ExD is unilateral from the UD to the ExD for cybersecurity protection of the aquafarm along with other cybersecurity protection measures.

5.4.1.3 External users and external organizational users

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From the reference architecture perspectives, external users and external organizational users do not belong to the UD. As they are categorized as "users", they are shown in 5.4.1 for information only. For the descriptions of the external user and external organizational user, refer to 5.4.7.1, which gives detailed roles and privileges.

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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	An aquaculture business's employees authorized to manage, operate, and maintain aquafarming facilities, systems, platforms, etc. These users are responsible for safe, reliable, and secure (both physical and cyber), reporting, etc., to continuously run the aquaculture. The manager users are responsible for aquatic product sales and price determination, supplier management.
User equipment (UE)	UE includes desktop and laptop computers, tablets and smartphones that are used by the users to operate and manage the aquafarming facilities, systems, and any other activities related to the aquaculture business.
User interface (UI)	UIs are graphical user interfaces of SW tools and utilities and applications including, but not limited to, visualization tools, analytical and statistical tools, cybersecurity tools, predictive and condition monitoring tools, system historical trending tools, data storage and archiving tools, reporting tools, and graphical presentation tools, etc.
Dashboard and visualization	The dashboard presents the overall summary of the aquaculture operation status, visually displaying selected parameters for the operation and business management. The operational status of all critical systems 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 and external organizational users	Refer to 5.4.7.1.

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