ATLAS: Internet of Things Platform for Precision Aquaculture

Vasilis K. Papanikolaou
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
GR-54124 Thessaloniki, Greece
vpapanikk@auth.gr

Sotiris A. Tegos
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
GR-54124 Thessaloniki, Greece
tegosoti@auth.gr

Pavlos S. Bouzinis
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
GR-54124 Thessaloniki, Greece
mpouzinis@auth.gr

Dimitrios Tyrovolas
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
GR-54124 Thessaloniki, Greece
tyrovolas@auth.gr

Panagiotis D. Diamantoulakis
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
GR-54124 Thessaloniki, Greece
padiaman@auth.gr

George K. Karagiannidis
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
GR-54124 Thessaloniki, Greece
geokarag@auth.gr

***Abstract*—The rapid growth of fish farming and production has led to the need for precision aquaculture. Concurrently, emerging cutting-edge technologies such as Internet of Things (IoT), cloud services, and artificial intelligence (AI) promise to overcome the challenges in fish farming and provide continuous monitoring, data analytics, and decision-making. In this work, we propose the ATLAS IoT platform which is designed specifically in order to meet the demands of precision aquacultures. More specifically, the ATLAS architecture is presented with its respective components, which are notated as the architecture's layers and they are described in detail. The ATLAS platform utilizes the synergy of IoT, cloud services, AI, and data analytics in order to capture the heterogeneous requirements of an automated aquaculture monitoring system. The latter entails the data collection, the data transfer, the design of communications schemes, energy efficiency provision, intelligent services, the pro-active decision making, and, finally, the creation of a user interface. Ultimately, the amalgamation of the aforementioned components creates the ATLAS platform, whose goal is to optimize the fish farming procedures.**

***Index Terms*—Internet of Things (IoT), precision aquaculture, data analytics, system architecture**

I. Introduction

AQUACULTURE, in combination with agriculture and animal husbandry, has been the primary means of production for centuries, while in the last decades they all have evolved in order to meet the increasing demand for maximizing productivity [1]. In particular, modern fish farming requires continuous actions towards addressing environmental degradation, overcoming diseases and parasite outbreaks, and maintaining the water quality at optimal levels [2]. Moreover, in order to further enhance the efficiency of fish farming, the timely detection of sudden changes in the ecosystem's state is of paramount importance, since, otherwise, they may lead to economic damage and product quality deterioration. Consequently, improving efficiency with accurate methods becomes increasingly necessary for the development of the modern aquaculture industry.

In fish farming, water quality is one of the most crucial factors which affect cultivation and production. Specifically, water quality can be characterized through physical, chemical, and biological variables, such as water temperature, pH, salinity, dissolved oxygen (DO), etc., which are subject to constant deviations and, thus, they can disturb the balance of the aquaculture's ecosystem. Traditionally, water quality monitoring relies on the manual collection of samples and their transport to laboratory units for further analysis, leading to increased financial and human resources [3]. Furthermore, by invoking traditional water monitoring techniques, it is particularly difficult to observe changes in water quality, as the samples are collected over relatively long time intervals and, thus, hinder the extraction of useful "trends" that may occur, due to the limited availability of samples. To address this challenge, the integration of the Internet-of-Things (IoT) technology, data analytics, and artificial intelligence (AI) can pave the way for the development of intelligent systems, which aim at the real-time monitoring and prediction of environmental parameters in fish farms, as well as in the provision of early-warnings when encountering abnormal behaviors

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[4]. In particular, with the aid of wireless sensor network technologies, the continuous control and efficient management of water quality can be ensured by monitoring the occurrence of adverse conditions that may be harmful to the aquaculture organisms [5]. Therefore, the efficiency of the aquaculture can be enhanced through automated systems that receive and process measurements from a distance, without requiring their on-site management.

In this direction, in order to improve the efficiency and the accuracy of the data collection process in an aquaculture environment, it is imperative to utilize an automated system that collects environmental data to record physical changes in real-time, as well as in the long term. These data can be retrieved and analyzed at any time, in order to extract useful information about the state of the ecosystem and enable the remote monitoring of the aquaculture. Additionally, through automated processes, it is possible to achieve the independence of the fish farming control process from human presence and, thus, reduce the probability of error due to human factors. Furthermore, through high-precision sensors, communication technologies, and pro-active decision making, it is possible to maintain the water quality at the optimal levels, hence, satisfying the underlying requirements for the welfare of aquatic organisms, which leads to economic profit increase.

In the existing literature, several works have proposed automated systems for aquaculture monitoring. For instance, in [6] and [7], a central processing core was utilized to process the collected data in the aquaculture environment and interact with the user terminal device. In [8], a smart aquaculture system was presented, where the control and monitoring was based on if-this-then-that rules and cloud integration. Moreover, in [9], the authors proposed an IoT system architecture for water quality monitoring, while they emphasized on describing the hardware and software components design. Also, in [10] and [11], an IoT-based aquaculture monitoring system was designed with the aid of cloud services.

Unlike to the aforementioned works, we focus on presenting a detailed system architecture for precision aquaculture, by defining the respective architecture layers, as well as the specified components which compose each layer. Our approach aims to capture the heterogeneous requirements of an automated aquaculture monitoring system, through cutting-edge technologies, e.g., IoT networks, wireless sensor nodes (WSNs) and actuators, cloud services, etc. To this direction, the ATLAS platform integrates the aforementioned technologies and designs the respective synergy and interaction among them. To this end, the ATLAS platform focuses on:

- Efficient data collection and transfer through dedicated communication protocols.
- Extracting useful information about the state of aquaculture through the processing of the received data by appropriate algorithms, e.g., machine learning techniques.
- Optimal decision-making for the aquaculture's sustainability via optimization algorithms, which contribute to the network's energy efficiency enhancement.

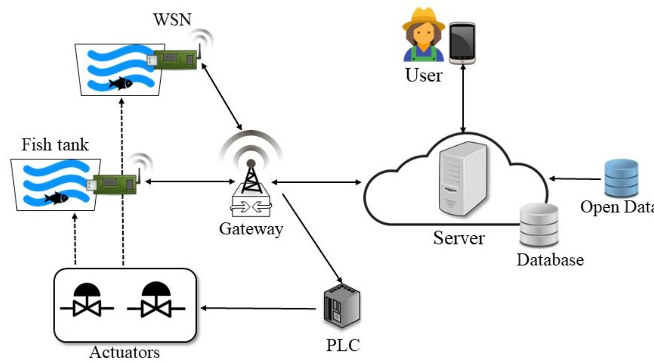

Fig. 1. System Layout

- The creation of an easy-to-use and user-friendly interface, which provides all the necessary information reflecting the current and future state of the aquaculture. Moreover, the control of the aquaculture in real time from a remote point is enabled.

II. System Architecture

The ATLAS system architecture is driven by the support of real-time operations. In Fig. 1, the proposed system's layout is illustrated. The WSNs measure the water quality parameters and the collected data are transferred to the cloud server through the gateway. Following that, the server is responsible for processing the received data, storing them, and performing certain functions for data analysis, decision-making. Finally, the actuators perform the corresponding actions with the aid of a dedicated controller, e.g., opening the oxygen pump, according to the determined decisions of either the server or the user through the user interface, which also presents the current and future state of the aquaculture.

In order to achieve all of the above, it is necessary to design an appropriate architecture that ensures the collection of the data of interest as well as their reliable transfer, the communication protocols, the data processing, the optimal decision-making based on the analyzed data and, finally, the availability and visualization of all the critical information to the user of the application. Therefore, the ATLAS system architecture consists of four distinct layers, which are illustrated in Fig. 2 and presented below.

- **Physical Layer**: It refers to the system's physical entities, which are the wireless sensor nodes (WSNs), the gateway, the programmable logical unit (PLC) and the actuators. Through the deployed WSNs, the water quality parameters are collected, and afterwards, they are transmitted to the IoT gateway which consequently forwards them to the cloud server. In addition, the actuators as well as its control units, i.e., the PLC, whose role is to carry out specific actions in order to maintain the state of the ecosystem at the desired levels.
- **Communication Layer**: It includes the communication protocols used for all the communication processes such as the information exchange among the WSNs and the

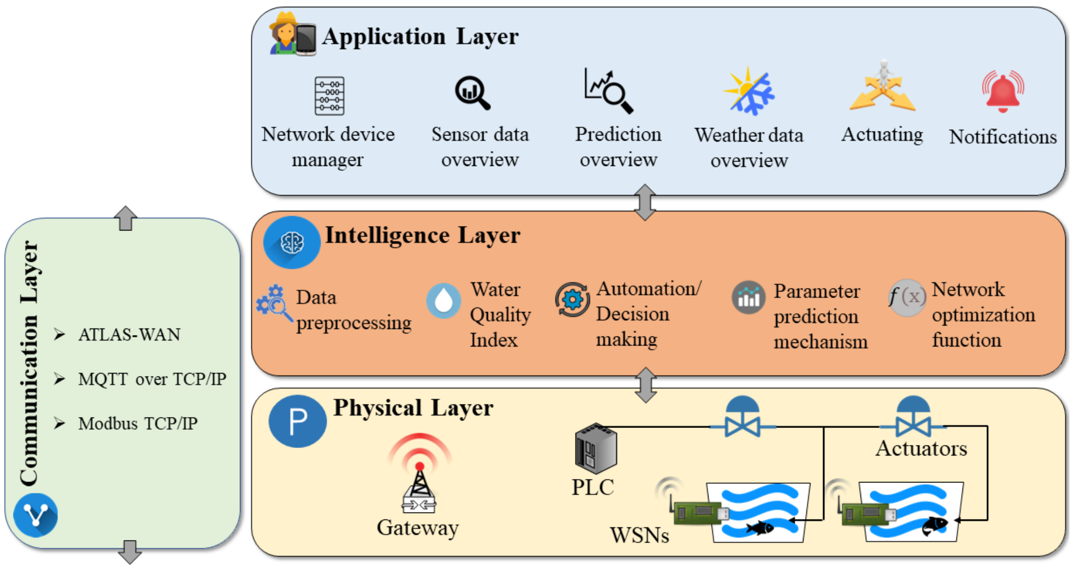

Fig. 2. ATLAS Architecture Layers

gateway, the communication between the gateway and the server, and the appropriate actuators' activation based on the received data. The communication layer is in line with the resource allocation performed by the intelligence layer, e.g., setting the transmitting power to the optimal level for energy efficiency and the admission control signals of the system.

- **Intelligence Layer**: It includes all the intelligent operations carried out on the server through the utilization of the data received from the sensors. These functions aim to extract useful information about the environmental status of the aquaculture, such as the forecasting of future states and the extraction of the water quality index (WQI). In addition, at this layer, decisions are made that aim at the optimal management of the network, such as increasing the system's energy efficiency. Finally, it contains services that aim at real-time supervision and reliable assessment of the aquaculture's state, as well as at making optimal decisions for the energy-efficient system operation.
- **Application Layer**: It contains the interface of the ATLAS web application, which can be easily accessed through any device with internet access. Specifically, it is responsible for creating appropriate interfaces through which the user can be informed about the system's condition and the water quality parameters, have access to a visual representation of the aquaculture's current and future condition, manage the network's devices, take actions and receive notifications.

III. Architecture Layers

Each layer of the ATLAS architecture consists of distinct hardware or software components that are responsible for performing certain functions. Below, we describe the elements which compose each architecture layer.

A. *Physical Layer*

The physical layer of the ATLAS system architecture consists of the hardware components used to maintain the efficient operation of the aquaculture. Specifically, it includes all nodes used i) to measure water quality parameters, ii) to control fish farming and maintain water quality at optimal levels, and iii) to transfer information packets between the nodes of the system. It should be mentioned that the physical layer groups all the components that are responsible to transmit and receive information, without requiring computationally expensive data processing. As aforementioned, the physical layer of the ATLAS system contains i) the WSNs, ii) the IoT gateway, iii) the PLC, and iv) the actuators. Below, the role of each component is described.

1) WSN: The WSN, which is depicted in Fig. 3, consists of all the sensors, that are responsible for measuring the water quality factors, e.g., DO, pH, conductivity, temperature, as well as a micro-controller and the transceiver which is responsible for either transmitting the data collected by the sensors to the gateway or receiving commands. These commands are used to perform certain regulating actions, e.g., adjust the sampling frequency and transmit power.

2) Gateway: The gateway is used to remotely interconnect the sensor network and the actuators with the server. Therefore, it constitutes a key node of the network, which is responsible for regulating the flow of data and communication between elements of different levels. To achieve this, the gateway should enable the usage of multiple communication protocols and conversion of the received data packets in the appropriate format for further forwarding, which constitute the main functionalities of the gateway. In addition, it can perform basic calculations and data processing.

3) PLC: The PLC stores instructions internally and performs control functions such as synchronizing, counting, and

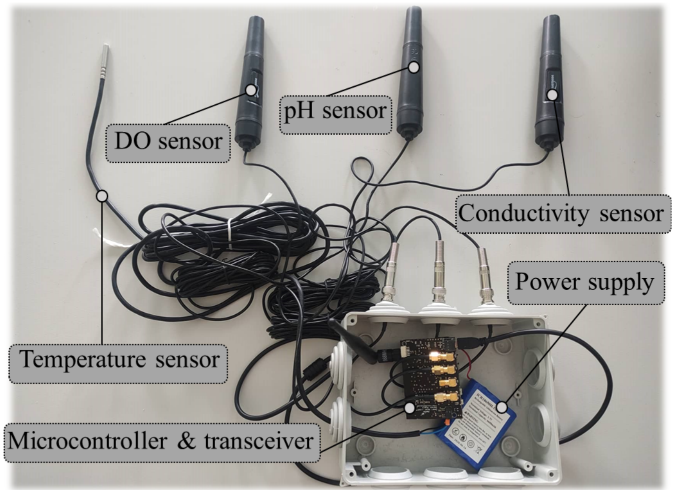

Fig. 3. Wireless Sensor Node

activating the actuators. Moreover, it is able to connect to gateways, thus enabling the remote reception of commands in order to activate the appropriate actuators. Specifically, the PLC processor receives data packets from external devices, e.g. the gateway, to its input ports and forwards control commands to the actuators which are connected to its output ports.

4) Actuators: The actuators are utilized to regulate the water condition and ensure the proper operation of the aquaculture, e.g., turn on water pumps, maintain the oxygen at desired levels, feed fish, etc., when deemed necessary by either the application or the aquaculture manager. The actuators are controlled through the PLC.

B. Communication Layer

The communication layer of the ATLAS system comprises the technologies utilized for the information transfer between the ATLAS nodes. There are three kinds of communication services supported by ATLAS, as presented.

1) ATLAS-WAN: ATLAS-WAN is the multiple access protocol utilized by the ATLAS network to support communication services between the WSNs and the gateways. ATLAS-WAN is built on top of LoRa functions of the nodes. A LoRa packet which includes all the sensor data is sent from the WSNs to a gateway, whereas the gateway can send control signals to the WSN, such as probability of transmission and transmit power. In ATLAS-WAN, these parameters are subject to optimization offering various configurations. More specifically, by default, ATLAS-WAN maximizes the energy efficiency of the network by statistically lowering significantly the number of collisions of LoRa packets and by using only the required amount of energy per transmission.

2) MQTT over TCP/IP: The MQTT over TCP/IP constitutes a serial communication protocol which is based on the use of the TCP/IP protocol and is responsible for the communication between the IoT gateway and the server. The gateway forwards all sensor data to the server and the server sends through the gateway all control commands to the nodes. MQTT is chosen for its particular low complexity and low energy requirements.

3) Modbus TCP/IP: The Modbus TCP/IP is a standard protocol for the communication between industrial electronic devices and controllers based on the internet protocol TCP/IP and, in ATLAS, is used for communication between the gateway and the PLC. Specifically, the data exchange between the gateway and the PLC is based on master-slave logic where the master requests data through a special request and the slave sends the response. In more detail, when the gateway sends a message in order to turn on an actuator that is controlled through the PLC, it sends a message containing the address of the actuator which is given by the PLC, the information data, as well as data for error correction. It is worth noting that all the actuators connected to the PLC can see the message, but only the actuator with the appropriate address responds.

C. Intelligence Layer

The intelligence layer is essentially the "brain" of ATLAS platform and is equipped with data processing, AI and optimization services. Specifically, the components of the intelligence layer are the following:

1) Data Preprocessing: The data preprocessing aims to prepare data for processing applications such as parameter prediction and the extraction of the WQI. Some examples of data preprocessing are filling in missing data, detecting and correcting errors in data measurements, regulating the sampling frequency based on the requirements of the parameter prediction mechanism, etc.

2) Water Quality Index: The WQI constitutes a metric that takes into account various water quality factors and integrates the overall information from them into the value of a unique integer index. Therefore, the WQI characterizes the overall condition of the water quality. For example, the WQI can be interpreted as "excellent", "good", "fair", "poor", "bad" which can be matched to the integer values "1", "2", "3", "4" and "5", respectively. The derivation of the WQI is based on fuzzy logic theory [12].

3) Automation/Decision making: Based on the values of the measured parameters, a decision is made for performing certain actions, e.g., activate the oxygen pump if the oxygen level is below or above specified limits. It should be highlighted that these decisions will be transferred to the PLC and actuators through the gateway, where the corresponding actions will be actually realized. Also, warnings are saved when encountering extreme scenarios, which can notify the application user. Moreover, decisions may rely on the extracted value of the WQI.

4) Parameter Prediction Mechanism: The parameter prediction mechanism aims at forecasting the future conditions of the aquaculture, e.g., predicting the temperature, DO, etc, in a specified time frame ahead. Its operation is based on the use of machine learning techniques and, specifically, on deep long short-term memory (LSTM) neural networks, which are trained offline in a supervised manner, where the past measurements constitute the training dataset. It should be highlighted that through the data preprocessing component, the input data, that are fed to the neural network, are converted in a suitable form. It is also clarified that for the prediction of each separate water quality parameter, a dedicated neural network is trained. Finally, as long as the database is filled in with new measurements, the neural networks can be retrained in order to increase their accuracy.

5) Network Optimization Function: Through the intelligent functions at this layer, the ATLAS system can adjust its resources to support various functions. The default function aims at minimizing the power consumption of the network nodes, while also satisfying the communication requirements of the system. Its operation relies on regulating resources such as transmission probability and transmit power of the WSNs. On top of that, additional functionalities include assigning higher priority to a WSN, as a way to guarantee its performance.

D. Application Layer

The application layer contains the interface of the ATLAS web application, which can be easily accessed through any device with internet access, e.g., smartphone, laptop, etc. For the interconnection between the application and the cloud server, an intermediate level application programming interface (API) is developed, through which the application has access to all the server's functions, such as managing network devices, accessing incoming data packets stored in the system or sending commands to the network's devices. Below, the web application's features are presented which aim at the accurate monitoring of the aquaculture as well as at the improved user experience.

1) Network Device Manager: Through the network device manager, network monitoring is provided. In particular, it allows the application user to manage the network devices, e.g., adding or removing a node, as well as configuring the basic operating parameters of the measurement terminal devices. For instance, the user can regulate the sampling frequency of the sensors' measurements or select default values.

2) Sensor Data Overview: The data overview component is responsible for presenting the real-time status of aquaculture by displaying the measured parameters, and hence, assist in the optimal decision making about the actions that need to be performed. Moreover, it enables the review of the history of the measurements, which allows the application user to obtain more insights about the status of the aquaculture. Furthermore, the overview of the WQI provides more comprehensive information of the overall conditions. For instance, an illustrative example of the WQI throughout a 24-hour time period is demonstrated in Fig. 4.

3) Prediction Overview: Through the prediction overview component, the application user can observe the forecast charts of each measured parameter, as well as the WQI over a 12-hour period. In Fig. 5 and Fig. 6, illustrative examples regarding the prediction of temperature and pH values are presented. The prediction mechanism, which is based on LSTM neural network, observes the state for 48 hours and

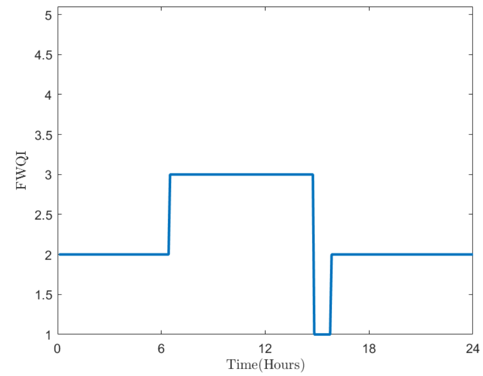

Fig. 4. Example of WQI overview.

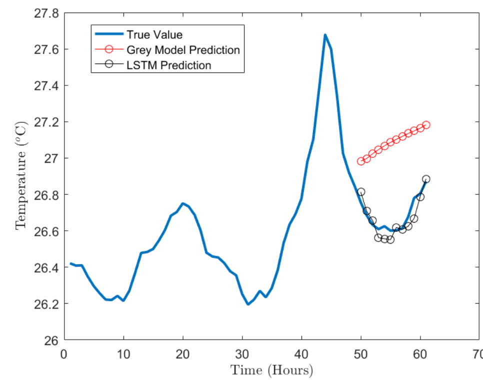

Fig. 5. Example of temperature prediction.

predicts 12 hours ahead. For comparison purposes, we also present the Grey model method, which fails to extract accurate prediction and, thus, the LSTM approach is adopted. The dataset used in these examples is available on [13].

4) Weather Data Overview: Any deviations in the weather conditions can greatly affect the state of the aquaculture. Therefore, weather data from weather stations can be used in a forecasting model of the system's needs. At the same time, to

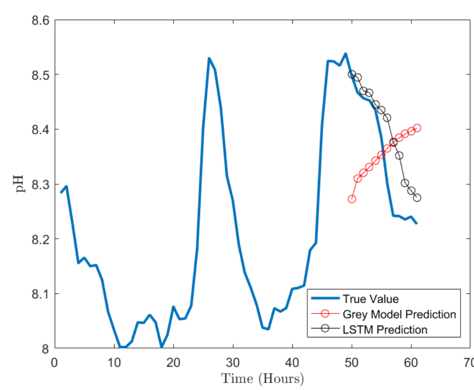

Fig. 6. Example of pH prediction.

improve the reliability of the forecast model, data from various meteorological stations are used, which can be evaluated by the user. Thus, through the weather data overview, weather data from open data sources are obtained for the aquaculture area and their impact on the water quality is assessed.

5) Actuating: Actuating includes all the actions that the application user can perform through the ATLAS interface such as feeding, oxygen injection, water temperature monitoring, etc. Specifically, the user can define the desired action as well as its duration, and then, through the API, the command is sent to the corresponding node that performs the desired action. However, the server of the ATLAS platform enables automatic actions based on the intelligence layer, in case where the user does not use the application and the water quality needs to be fixed.

6) Notifications: Notifications are forwarded by the application to the user to notify about

- The value of a metric that exceeded the allowed limits.
- The WQI received values that indicate the poor water quality of the aquaculture.
- The actuators that are in operating mode.

In case of any anomaly in the water quality metrics, the ATLAS platform asks the user if he wishes the system to perform some automatic actions by itself or not. Therefore, the execution of an action is at the discretion of the user who can either accept the proposed actions of the system or declare which actions he wants to be performed.

IV. Conclusion

In this paper, we proposed the ATLAS platform, which is based on an architecture of four distinct layers, and enables the observation and control of aquaculture with stringent operational constraints, in a unified and automated manner. Moreover, the ATLAS platform aims to capture a wide range of scenarios, thus its design targets generalizability. Finally, the proposed architecture can serve as a baseline for more sophisticated applications in precision aquaculture, which require additional components, functions and services.

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