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SMART ELECTRONIC SYSTEM FOR MONITORING WATER QUALITY PARAMETERS IN FISH TANKS

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ABSTRACT. Fish farming represents a strong link in the value chain of food distribution over the world. There are different types of farms like RAS, continuously water alimented pounds, lake, maritime, etc. The self-cleaning water capability of a tank system is the key factor in describing RAS (recirculating aquaculture system) systems. This factor is crucial for the survival of farmed fish in urban aquaculture systems. The aim of this paper consists in describing the design and the functionality of a smart electronic system, capable of monitoring water quality parameters, in order to monitor the fish tanks' environment and making decisions about undesirable events that may affect them. If unpleasant events occur, such as the parameter's level no longer falls within the preseted limits, an alarm is set to warn the user. Automatization of the system will be conceived to close the power and/or water supply circuit in case there was no human intervention within a certain period of time in the fish tanks. This paper is based on the ongoing research of the iPREMAS aquaculture project. The system from the iPREMAS project contains sensors for monitoring the essential water quality parameters for the growth, reproduction and qualitative and quantitative improvement of fish population, such as pH level, water temperature, dissolved oxygen level, water salinity, water level, conductivity and will be improved with sensors to monitor the level of nitrates and nitrites. The sensors are to be connected to a special designed electronic module and will transmit the information to an electronic control module based on a development kit containing a microcontroller for the automatization of the system. A database is used to store the data and a software application is used to visualize the data transmitted by the sensors that will communicate with the database and display the values in real time.

Keywords: Water quality, sensors, aquaculture, intelligent monitoring system, fishfarm monitoring platform

1. INTRODUCTION

Various tools are emerging from both the underwater acoustic sciences and fishery engineering, and we can fully utilize them. Subsequently, we are expecting a

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quantum leap in areas of interdisciplinary fishery acoustics, aquaculture monitoring system, underwater object monitoring, underwater fishery surveillance, and many more applications for fishery businesses. Further, there are expected abundant technical touches on various scientific and engineering topics on principles and applications of fishery acoustics, including, but not limited to, the following:

- Fish finding and stock assessment using underwater acoustics;
- Robust fishery detection/estimation for fish stock assessment;
- Intelligent signal processing systems for fishery acoustics;
- Information processing and intelligent signal processing techniques for fishery;
- Underwater fish tracking and surveillance systems;
- Devices and systems for fishery stock assessment;

Nowadays, the optical sensors addressed to in-situ measurements of chemical and physical parameters, represent the newest technologies envisaged to be used for real time monitoring of water sea environment. They have small volume sample, high sensitivity with good detection limit and selectivity. An optical sensor fulfils the following parameters: stable and accurate reading over time, well define response time exhibiting a membrane with fouling resistance. Dedicated adaptations are required to implement such optical sensors for easy, reliable and quick use in aquaculture. The optical and optical fibber sensors are especially used in continuous monitoring, quantity measurements and analysis of underwater gases such as: NO2, NO3, NH3, and dissolved O2, CO2. These gases are present in the marine environment due to microorganism fermentation (dissolved O2, CO2), pollution, organic waste matter decomposition, gas exchange with the atmosphere, animal and human waste or nitrogen fixation processes. When the NO2, NO3, NH3 toxic gases are present in water sea environment at high enough levels, it is difficult for aquatic organisms (fish, shells, etc.) to sufficiently excrete the toxicant, leading to blockage of internal organs and potentially death.

Therefore, the real time monitoring of these gases with high sensitivity is mandatory for fish and shell farms. iPREMAS will focus on answering following research questions related to monitoring parameters:

- identifying and testing cost effective and reliable monitoring schemes relying on IoT technologies paying attention to how to equip and design an offshore infrastructure to robustly integrate sensors.
- identify which parameters can be continuously measured and provide a reliable description of a) the overall condition of the farm and b) give a good prognosis of the maintenance needs.

The project proposes novel low-power sensor probes for:

- UV-VIS water quality spectroscopy (based on sensors from Hybrid_VLC-IR-RF project, TRL5)
- aquaphones for fishery bioacoustics
- Vibro-acoustics of tractive forces.

The sensor parameters will be improved and optimized in order to achieve the detection limit appropriate to monitoring the key water parameters. Instrumentation and telemetry Communication can comprise several networks with different sensors that send data to a sink node via ZigBee from which it is forwarded through mobile communication (2G/3G/4G) to a server through internet. Networking protocols and standards were proposed for marine monitoring such as Salman and Jain (2017), but are not plentiful enough for all applications in this environment. In this environment it is important for IoT devices to have energy harvesting devices (e.g. PV panel), and GPS localisation besides the water quality sensors. Data analysis and predictive forecasting Information fusion (IF) provides methods for (semi)automatically transform data from different sources and times into representations supporting human or automated decision making (Bostrom et al., 2007). It has wide applications and growing research efforts in sensor integration for aquaculture (Hassan et al., 2016).

2. STATE OF THE ART

In the aquaculture system, fish are cultivated in artificial water bodies that are enclosed, such as tanks, where they can dwell, feed and grow. Since there is no natural source of water, the water quality soon deteriorates, which has an impact on the development of fish. Therefore, the aquaculture system's reliance on good water quality to ensure the optimum development and health of fish is crucial (Tamin et al., 2022).

An example of developing a monitoring system for the water quality parameters is: “IoT based smart agrotech system for verification of Urban farming parameters” paper, where there were considered the pH level, water temperature, dissolved oxygen level and others as significant aquaculture farming characteristics. Using this technology, fishermen may evaluate the various aspects of water quality and keep an eye on the wellbeing of fish. After analyzing the data received from sensors fish farmers are able to take necessary steps in order to provide proper healthy water for the healthy living of fish (Podder et al., 2021).

Buck et al. (2017) described an analogue effort including more species and the results of applying force sensors in a mussel longline demonstrator setup. iPREMAS focuses on tackling the great need for developing additional knowledge in cost effective monitoring techniques for multiple physicochemical parameters. Marine environment sensing is an IoT-based area for monitoring physical biochemical and structural parameters water quality, waves and currents, etc. Although a main challenge is delivering robust Data Transmission, modern offshore wind turbines, can cope with huge number of sensors (Guobao et al., 2019).

For water quality monitoring either electro-chemical sensors or optical (NDIR NonDispersive InfraRed, NIR, Fluorescence or Optode) are used (Lindblom, 2009). The expanding aquaculture is a critical contributor to food security worldwide. Animal welfare and ethical aquaculture methods are essential to achieving sustainable production and maintaining consumer demand. There are numerous stress factors to animals held in captive aquaculture systems and, while their effects vary, if not correctly managed these typically lead to poor wellbeing and compromised fish health, ultimately affecting economic profitability. Certain stressors associated with aquaculture may be unavoidable, and the fundamental goal for successful growth and production is the optimisation of strategies and practices to effectively manage or mitigate stress. One stressor of increasing interest in aquaculture is noise from biotic, and more significantly, abiotic, and anthropogenic sources (Lucas et al., 2012).

The emergence of Industry 4.0 incorporating smart systems, machine learning (ML), artificial intelligence (AI) and predictive maintenance (PdM) allows industries to monitor industrial equipment in real time (Cinar et al., 2020). PWC reports that about 11% of the surveyed companies “do” predictive maintenance based on ML (Seebo, 2019). Although the aquaculture sector was not included in the survey, it is well known that PdM is not applied within the sector. Successes within the (mainly on land) industrial sector demonstrate that introducing PdM in aquaculture could increase benefits substantially. The research question comprises identifying which are the most reliable methods for predicting overall health and need of maintenance based on real time monitoring. The question will be answered within iPREMAS, by researching predictive assessment and focusing on searching feasible methods for time series forecasting, modelling (anomaly) symptoms based on gauged (and forecasted) data to represent an operation state (Pedersen et al., 2016). Proven ML algorithms like Artificial Neural Networks (ANN) and Support Vector Machines (SVM) will be tested and adapted for detecting degradation on aquaculture parameters and infrastructure.

3. EXCELLENCE

Marine Aquaculture (fish, mussel, oyster and seaweed) is among the emerging sectors of the blue economy. The interest in marine aquaculture production keeps increasing due to the wide potential on food security, derived compounds and their bioactivities (Garcia-Poza et al., 2020). Due to the growing interest to move large scale aquaculture operations further out into the open ocean the need for new solutions to tackle the challenges of the harsh and exposed environment increases (Troell et al., 2009). A novel approach is replacing monoculture systems by integrated multitrophic aquaculture (IMTA) to solve environmental issues such as eutrophication (Granada et al., 2016). Remote control, predictive maintenance as well as smart infrastructure are crucial for large scale commercialization.

The project “Intelligent PREdictive Maintenance for Aquaculture Systems” is a research project aiming to improve the performance of aquaculture farms by introducing a novel platform and service for Intelligent predictive maintenance. The platform is based on innovative monitoring systems and smart infrastructure, relying on Machine Learning (ML) and Artificial Intelligence (AI) techniques.

The platform measures key parameters in real time introducing innovative multi-sensor gauges which feed a chain of ML models for Time Series Forecasting (TSF), Anomaly Detection (AD), Fault Classification (FC) and Remaining Useful Life (RUL) estimation. The measurements give the current health status of the farm site while the forecasts provide a glimpse of future status; analysis of the predictions allow to identify the potential need of preventive/corrective maintenance.

A cloud-based integration of the different components of the platform allows to improve connectivity and safety while optimizing the business process which lets the farmers benefit from a tailor made Software as a Service solution. The SaaS approach empowers the aquaculture farmers by providing a digital twin of their facilities ‘in their pocket’. Blockchain technology will be used to provide trust and traceability, such as securely managing the sensor data information as well as the identity of the stakeholders. Security and privacy compliance with GDPR will be ensured by implementing reliable, secure data transport and access.

The main objective of iPREMAS is to develop a platform and service for Intelligent predictive maintenance of aquaculture systems based on innovative monitoring systems and smart infrastructure, relying on machine learning and artificial intelligence techniques. These elements will form a customized Farmer Support Service (FSS) allowing the aquaculture sector to operate and control remotely.

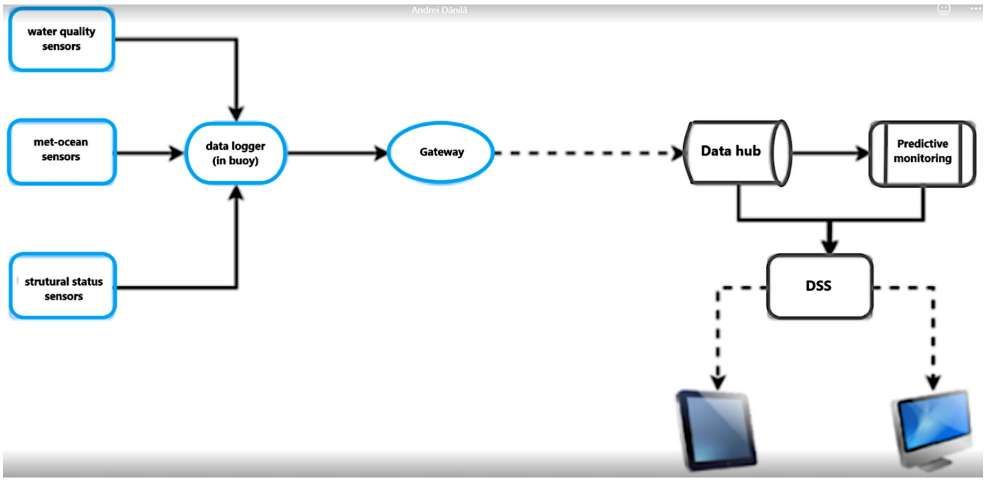


Fig. 1. ***High level system diagram of the proposed iPREMAS architecture***

Fig. 1 presents the high level system diagram of the proposed iPREMAS architecture. The main innovation part of this system is that it can measure a great variety of parameters, it allows the sensors to be interchangeable and also permits that other sensors to be integrated into the system (e.g. sensosrs that farmers already have and use).

4. METHODOLOGY

The strategic objectives of iPREMAS are to investigate the development of predictive maintenance algorithms and Farmer Support Services, based on key monitoring parameters. The iPREMAS solution and monitoring protocol is curently piloted, tested and validated on three selected sites.

Key survivability parameters per species were defined taking in account production practices. Our common network with partners in aquaculture allowed us to quickly identify and follow the state of the art, in terms of evolution of the sector and monitoring needs. Key maintenance and operation parameters were identified, these are considering technical/ technological practices for production. Anomaly indicators are being sketched based on operational practises. Techniques for defining intervals for good operation/survivability condition and thresholds for anomaly detection are being investigated and applied.

Next phase deals with designing and developing a robust sensing system based on the actual findings. Data from the sensors is combined with data from equipment (pumps, dissel generator, PV system, etc.) to perform context and anomaly recognition. Protocols will include: requirements engineering, standards compliance; operational system concept; and IoT, sensor device connectivity, data management layer.

Aiming for animal welfare and ethical methods, we intend to monitor parameters as: dissolved oxygen, temperature, pH, suspended solids, water lavel, nitrits and nitrats etc to improve operational practices.

The behaviour of the monitored data are studied first. Relying on approaches like behavioural analytics, underlying functions will be derived. Now, several ML techniques (ANN, SVN, etc) are being investigated to make forecasts with a lead time of up to 5 days. Following, the analysis will focus on: systematic degradation and detection of anomalies to optimize maintenance; this stage will need long gauged series.

The architecture of the system has 3 components: data gathering, data modelling/analysis and warning. In this stage an operational cloud-based prototype is up & running in the Ovidius Aqualine pilot. The data gathering component is a network of IoT components (energy independent sensors, gateways and routers). The system, is sending the information from the sensors to a central node (WiFi) reaching Cloud/Edge over mobile communication.

The data modelling/analysis developed will be wrapped up next for the operational cloud based implementation. Warning relies on a functional analysis based on data sharing in workshops with farmers and stakeholders from the sector. Our network based on both individual contacts and via the cluster organizations and sector organizations (aquaculture, seaweed, etc.) within the North Sea, Black Sea, Algarve, etc. will be essential for outreach with impact. The warning module is relying on microservice architectures and Open Source. The system was demonstrated to farmers participating in the previous workshop (Fig. 2).

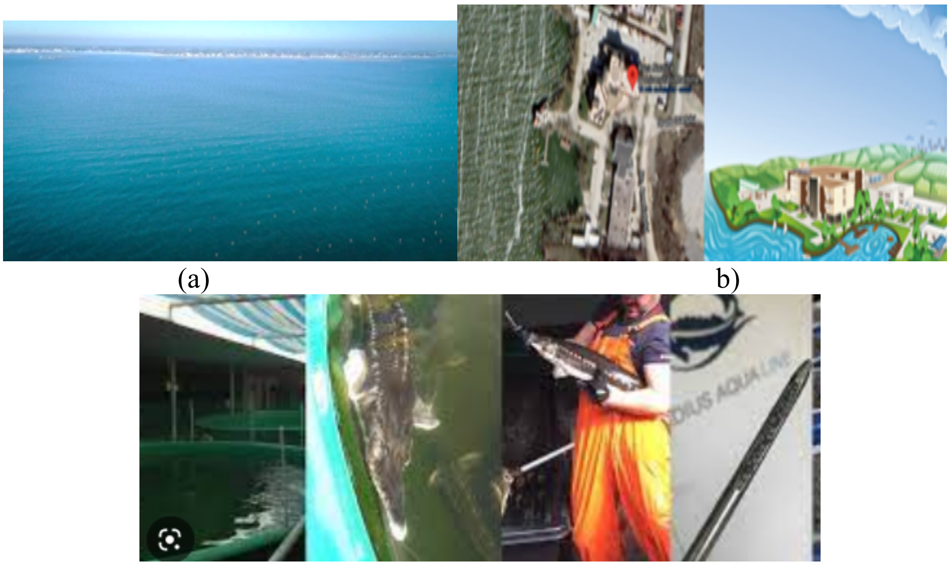
(a) (b)

Fig 2. ***(a) Fish gender determination, (b) Fish disection and observation***

The test group will be invited to regularly follow up the system and share their findings/experiences/remarks in later workshops. Findings during these workshops will be taken to improve following versions of the system.

5. USE CASES

iPREMAS will be implemented and tested for industry and experimental validation on the ecological aquaculture farm Ovidius Aqualine, on a testbed within the Black Sea University in Constanta and on an off-shore aquaculture farm in France. The three pilot sites have distinct features and requirements to show the versatility and flexibility of iPREMAS, and also give a perspective on the scalability with a view to the future exploitation of the results (Fig. 3).


(a) b)

c)

Fig. 3. ***(a) ALGOLESKO, (b) CONSTANTA MARITIME UNIVERSITY, (c) OVIDIUS AQUALINE***

ALGOLESKO – A 150 hectares farm in the open sea, in the heart of a Natura 2000 classified site. Seaweed is cultivated in preserved waters off Lesconil, Frnace. From reproduction to harvest, the cultivation cycle guarantees authenticity, quality and traceability. 100% of the production is certified organic.

CONSTANTA MARITIME UNIVERSITY - the nautical base of CMU has a multifunctional laboratory consisting of 12 stands serving a number of 15 disciplines from the curricula of the University, including engineering, aquaculture and environmental protection in industry

OVIDIUS AQUALINE – is a fishfarm located on the Danube bank in Borcea locality, Calarasi county, carries out its activity in a precinct (yard) of 1500 sqm. In this enclosure is located a hall with an area of 600 square meters, thermally insulated, divided into growing space, storage space, roe and meat processing space (authorized DSV) and offices. Within this farm, sturgeon species (beluga-Huso Huso, sturgeon-Acipenser gueldenstaedtii and stellate sturgeon-Acipenser stellatus) and trout, both breeding adults and spawn are raised for sale. All the results presented in this article are obtained in this Pilot.

For the optimal configuration of the system to be implemented in Ovidius Aqualine pilot, stress factors in precise context were identified in Table 1.

Table 1. Stress factors and their causes

No	Stress factor	Cause
1	Variations of dissolved oxygen percentage	Due temperature variations Feeding process Low water flow in the recirculant system
2	High nitrate levels	Feeding process Biofilter malfunction Low performance of biofilter
3	Low water recirculation frequency/debit	Mechanical malfunction Power outage
4	Low feed absorption and high mortality risk	Due to high water temperature during summer months

For the iPREMAS project, the water quality parameters to be monitored are: dissolved oxygen, pH, temperature, water level, nitrates and nitrites. Until now there has been installed a system composed from a Smart Water Extreme station from Libelium with these shelft available sensors/probes, but all the sensors from the requirement list will be installed as they will be available (Fig. 4):

Fig. 4. ***Installation process***

- PHEHT – Temperature, pH, ORP
- C4E – Temperature, Conductivity, Salinity and TDS
- MES 5 – Temperature, Sludge Blanket, SS (suspended solids), Turbidity
- VEGAPLUS C21 - Distance
- OPTOD – Temperature, Oxygen (%, mg/L and Ppm)

The data acquired by the sensors (every 20 min) are live transmitted to the cloud platform, and can be visualized using Grafana dashboard (Fig. 5). An alarming system has been developed for preventing water quality parameters to get out of optimal range. When a parameter gets out of range, a message is sent in the Telegram app, with a short description of the problem (e.g. Temperature is out of range 9°C – 16°C).

Fig. 5. ***Grafana dashboard***

6. CONCLUSIONS

The project iPREMAS and its outcomes (capacity, knowledge, methods and tools) fit naturally within the water, energy and food security nexus which is central to sustainable development. The outcomes from iPREMAS have potential to assist in developing a sustainable, integrated approach to cope with the inextricable linkages between these critical domains. The project results will contribute to the UN SDG 14 – Life below water, SDG 13 – Climate action, SDG 6 – Clean water and SDG 9 – Industry, Innovation and Infrastructure. Some examples are given below:

- **Environment**: Monitoring offshore structures allows preventing structural failures and detecting timely potential disasters. It reduces maintenance and operation (M&O) costs decreasing production risks and environmental impacts.

The real time monitoring has a significant potential for reducing the impact of spills and accidental releases

- **Climate**: Optimizing in operation costs leads to reducing on site deployments which are a relevant measure towards reducing GHG emissions. Strengthening the mariculture sector has a beneficial impact on increasing CO2 capture with nature as main driver.
- **Energy**: The potentials of predictive maintenance are the biggest for the offshore energy sector; by this means iPREMAS can assist building and operating resilient and sustainable renewable energy production sites. Facilitating the multi-use philosophy can help to generate additional revenues to energy producents by enabling alternative functions. Strengthening the production of seaweed can be of relevant importance towards the profitability of biofuels as alternative energy sources.
- **Food**: By assisting aquaculture farmers, the project is a step forward towards strengthening the sector and building for food security Reducing M&O costs can become a key measure to assist in scaling up the Flemish aquaculture as well as the European sectors. Real time monitoring may be the tool to increase yield and identify/introduce new profitable species.
- **Health**: iPREMAS's (remote monitoring) approach will also aim to lower significantly the human risk-factor associated with offshore operations by cutting down unnecessary site visits when the monitored status is fine.
- **Job creation**: Construction and M&O costs will be cut by remote monitoring and predictive maintenance. These efforts will allow developing resilient and competitive European blue economy while opening the way towards multi-functional developments giving a boost to job creation. Predictive monitoring and maintenance are a means for strengthening the marine sector which can lead to generating more work and economic activities with subsequent job creation.

iPREMAS provides advantages precisely due to the transnational character of the partnership. From the technical point of view both companies have gained solid expertise in different but complementary disciplines necessary for the project's development. Additionally, from the geographical perspective, each partner contributes with a wide network of clients and markets enabling iPREMAS to be introduced in west as in east Europa providing a better chance for innovation to enter new markets, by joining exploitation strategies.

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