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State-of-the-art and future needs

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Executive summary

Understanding the impacts of environmental change and human activity on farmed fish can be greatly enhanced by using electronic sensors. Indeed, many questions can only be answered through this approach. Electronic sensors are significantly improving our understanding of fish behaviour and are emerging as key sources of information for improving aquaculture management practices.

Enhanced environmental (e.g. oxygen, temperature, salinity, pressure) and biological (e.g. behaviour, activity, energetic, feeding physiology) sensor data, collected by a network of wireless electronic sensors, can provide accurate fine-scale measurements of environmental conditions, fish health, welfare and habitat use, average fish size and biomass, thus facilitating predictive modelling of the rearing performances and impacts.

The state of the art and future needs in terms of technologies, accessibility and integration is outlined in the present report.

The real-time wireless communication system and sensor network envisaged for the FutureEUAqua large scale demonstration activities will include a cloud platform that communicates wireless underwater, based on the technology offered by Real-time aquaculture (www.rtaqua.com). The system architecture includes "AquaMeasure" which is a family of compact, submersible environmental sensors with underwater and in-air wireless communications. While the "AquaHub" is the core of the system deployed in the field and can be easily mounted to existing aquaculture infrastructure or feed barges. Utilizing a digital receiver, communications modem and state of the art electronics, the AquaHub can support up to 100 AquaMeasure sensors (e.g. temperature, salinity, oxygen, turbidity, etc.) within a 500m radius. The AquaHub also supports the detection of signals from the family of VEMCO transmitters. Namely the V9AP & V13AP accelerometer pressure tags, which measure the fish activity, including swimming speed via tail beat acceleration, mortality through predation, seismic blasting, toxic spills, feeding events, spawning activity, nocturnal/diurnal activity, wave action and activity responses to changing oxygen, salinity and temperature in the rearing environment. The hub supports many telemetry protocols for cloud communications, including Cellular, Wi-Fi and Iridium. The wireless hub also supports third party sensors (e.g. weather stations, biomass monitoring, etc.) via its auxiliary sensor port and features internal memory for backup purposes.

In Annex 1 is reported a list of scientific publication, as well as grey literature and websites.

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Introduction

The study of aquatic animals (e.g. fish behaviour, condition, physiology) and the farming environment presents unique challenges to scientists because of the physical characteristics of water. However, scientific studies and efforts have increasingly turned to the use of electronic sensors, which have enhanced our knowledge on the performances of the farmed fish and the impacts on the surrounding aquatic system.

In their most basic form, electronic sensors and tags may include radio or acoustic beacons, that transmit signals, which can bring specific codes to identify animals, and allow them to be tracked using receivers that detect the transmitted signals (Hazen et al. 2012). Basic archival tags must be, instead, physically recovered in order to obtain the data.

Because the strength of radio signals, regardless by the longest wavelengths, rapidly attenuate in seawater, acoustic transmissions is preferred for fish tracking in marine environment (Lembo et al. 2002), while radio transmission is commonly used in freshwater environment. More advanced tags incorporate sensors that measure and record a suite of environmental and/or biological parameters of fish (Cooke et al. 2016).

Simple biomass estimators and logging stations, installed on the feeding barge and/or on the cages, can give full control over all water parameters and provide the information required to monitor/expand the production. Flexible sensors systems are conceived to log oxygen, temperature, salinity, sea current, pH, wind and CO_2. In addition, sensor and camera systems may provide also information for estimating the biomass in the cages and developing reliable fish feeding strategies.

Understanding the impacts of environmental change and human activity on farmed fish can be greatly enhanced by using electronic sensors. Indeed, many questions can only be answered through this approach. Electronic sensors are significantly improving our understanding of fish behaviour and are emerging as key sources of information for improving aquaculture management practices.

In WP5 we are committed to develop and test a multiplatform tracking system for simultaneously monitoring the activity and physiology of fish, as well as the main parameters of the environment where they are farmed, by using a wireless communication system.

The wireless communication system to monitor the large scale demonstration activities will both facilitate effective study design and replication, increasing the accuracy of data standardization, processing and interpretation (e.g., Kessel et al. 2014, Huveneers et al. 2016), and providing industry with information needed to facilitate health/welfare and optimal management practices. The development of training programs and guidelines for data assessment and monitoring, as well as data-sharing protocols, will facilitate easier data exchange among database and research groups.

In the following paragraphs the state of the art and future needs in terms of technologies, accessibility and integration is outlined.

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The state of the art

An integrated and interdisciplinary approach to monitor the activity pattern and physiological status of farmed fish, together with the environmental parameters *in situ*, will enhance the sustainability and profitability of the European aquaculture.

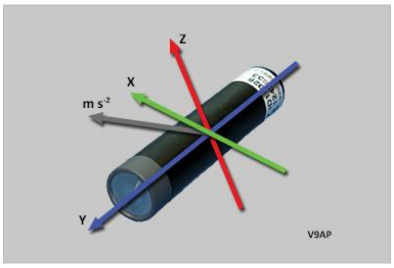
Enhanced environmental (e.g. oxygen, temperature, salinity, pressure) and biological (e.g. behaviour, activity, energetic, feeding physiology) sensor data collected by a network of wireless electronic sensors can provide accurate fine-scale measurements of environmental conditions, fish health, welfare and habitat use, facilitating predictive modelling (Cooke et al. 2016; Rassaei et al. 2014).

However, although sensors are widely used in terrestrial applications, their use in the marine environment and aquaculture was limited so far by the special attributes of water, the high cost of underwater sensors and malfunctions due to the harsh environment. Underwater sensors should fulfil certain characteristics in order to increase their use in aquaculture. Preferably, they should be of low cost, low maintenance, low-power (if battery powered), robust, waterproof, non-metallic, withstand their environment and have no effects on surrounding organisms (Parra et al., 2018).

Below we provide a state-of-the-art review of the current technologies in relation to a) fish tracking, b) environmental monitoring, c) biomass assessing.

Fish tracking

Accelerometer pressure tags transmit 3D acceleration of fish as they move within the receiver array, and also transmit depth data. The fish acceleration signal is measured in terms of m/s^{-2} and it is a vector quantity that is a result of measuring acceleration on 3 axes (X,Y,Z). This acceleration value can be used as a measure of activity of a free ranging animal in nature or captivity. Accelerometer tags can be used in a number of applications that require any measure of animal activity. Applications may include measuring swimming speed via tail beat acceleration, detecting mortality through predation, seismic blasting, toxic spills,



feeding events, spawning activity, nocturnal/diurnal activity, wave action and activity responses to changing oxygen, salinity and temperature in the environment. A commercial product is **VEMCO V9AP & V13AP** (https://www.vemco.com/products/v9ap-v13ap-accelerometer/)

The **VEMCO VR2W-180 kHz receiver** is cost effective, compact, easy to use, long-lasting and flexible, making it ideal for remote, long term monitoring of fish. The VR2W-180 kHz is used with the family of 180 kHz transmitters (V4, V5 and V9-180 kHz). The V4 and V5 enable to track and monitor smaller fish. The introduction of the V9-180 kHz tag has expanded VEMCO's 180 kHz capability to include longer life tags that can be used on larger animals. 180 kHz tags have

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been used widely on a variety of fish species, from salmon smolts to trout and arctic cod, from seabass to seabream.

The **VEMCO VR2Tx Acoustic Receiver** combines a VR2W receiver with a built in V16-like transmitter that allows communications with receivers while still deployed. The VR2Tx maintains all of the existing features of the VR2W plus much more. a) Improve VPS (fine scale positioning) results using the built in transmitter as a VPS sync tag; b) retrieve receiver status on demand from the surface via communications with a VR100 tracking receiver (models -200 and greater) and transponding hydrophone; c) monitor health, tilt angle, range, temperature, battery life and memory of deployed VR2Tx units; d) monitor number of total detections as well as specific tag IDs with the programmable watch table; e) determine which receivers are in range of the VR100 (unit discovery mode); f) locate potentially lost VR2Tx units.

The **Thelma Biotel Acoustic Activity Transmitter** (https://www.thelmabiotel.com/outputs/activity/) contains a 3-axis accelerometer that can register gravity forces and acceleration in the x-, y and z directions with very high sensitivity. The activity tag is available down to 7.3 mm diameter size, with a variety of battery options for different power output settings and lifetimes. The tag can register the tilt and roll angle of the fish, as well as motion in the forward and lateral directions. These key parameters reflect a broad range movement and activity patterns of aquatic specimens, that in turn can be used to study behaviour and/or welfare. Relevant movements include feeding or spawning behaviour, body tilt orientation, rest or activity level, comfort or stress state. The transmitter can for example be programmed to detect attacks against a prey, count how many times this movement signature is detected during a period of time, and transmit the stored number of detected movement signatures wirelessly.

The **Cefas Technology** G7 (https://www.cefastechnology.co.uk/products/data-storage-tags/g7/) enables to log temperature, pressure and acceleration. In the latest design holds a 3-axis accelerometer sensor, which allows the user to set the measurement range from ± 2, 4, 8 or 16 g at deployment time. An optional 3-axis gyroscope sensor is available. It has variable resolution, either 8, 10 or 12 bits. Operates in fresh water and at sea.

The **STAR ODDI logger DST milli-HRT** (https://www.star-oddi.com/products/data-loggers?sensors=heart-rate) monitors simultaneously heart rate and temperature in the fish. The data logger has no external wires, which makes it especially simple to implant. It is made of unique ceramic housing and epoxy and is hermetically sealed, guaranteeing biocompatibility. The logger is ideal for monitoring behaviour and stress response of the fish. The heart rate is derived from a leadless single channel ECG. The logger takes a burst measurement of ECG at the set time interval and calculates the mean heart rate for each recording. For validation purposes, individual ECG bursts can be saved.

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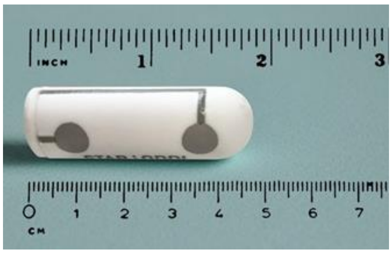
The **STAR ODDI logger DST centi-HRT ACT** simultaneously measures long term heart rate, activity and body temperature in the fish. The measuring device has no external wires, which makes it especially simple to implant. The logger is hermetically sealed for biocompatibility. It is ideal for monitoring behaviour and stress response, animal welfare and fish physiology. Looking at heart rate and activity together gives the opportunity to identify correlation between heart rate and activity in the fish. The heart rate is derived as in DST milli-HRT. The DST activity loggers measure acceleration in three dimensions, in relation to Earth gravity field. There are two modes for sampling, either at a single interval throughout the period or multiple intervals. Multiple intervals are especially useful when frequent measurements are needed at certain time periods.



The **Lotek coded electromyogram (CEMG2) transmitter** (http://www.lotek.com/cemg2-series-emg-transmitters.htm) represents one of the components of a field-proven system which enables to record physiological data from free-swimming fish. Designed to be mounted either externally or internally, CEMG2 transmitters measure muscle activity using probes inserted into the musculature of the fish. The CEMG2 Series provides you with a powerful quantitative estimate of the energetic costs associated with physical activity. High impedance EMG signals are processed through an integrator, digitized and then a coded radio sequence is transmitted representing unique identity and data. Electromyograms (EMGs) are records of bioelectric potentials that are strongly correlated with the strength and duration of muscle contractions. Indeed, EMG values averaged over time can be used directly as quantitative indicators of the intensity of fish activity. EMG values can be "calibrated" in terms of fish oxygen consumptions measured over periods of spontaneous activity or over the same times in swims of selected speeds and durations, by using a swimming chamber. This in turn allows to obtain quantitative estimates of the metabolic costs of activity by wild fish, under field conditions, and farmed fish.

MAP-Series acoustic transmitters are designed for operation with **Lotek's** unique MAP digital encoded telemetry systems. These systems permit the unique identification of over 80,000 individual fish. Both ID-only and ID plus sensors (temperature, pressure/depth or motion) can be simultaneously monitored and recorded. Unique CDMA coding permits simultaneous detection of hundreds of co-located transmitters at high repetition rates (to 40 transmissions per minute). Examples of real-time and/or data-logging applications for which MAP-Series coded transmitters are ideally suited are species interaction, fine scale 2D and 3D habitat utilization and fish behaviour.

Fish stress become visible: A new attempt to use biosensor for real-time monitoring fish stress
https://www.sciencedirect.com/science/article/pii/S0956566314007003?via%3Dihub

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To avoid fish mortality and improve productivity, the physiological conditions including stress state of the cultured fish must be monitored. As an important indicator of stress, glucose concentrations are monitored using in vitro blood analysis. The physiological processes of fish under environmental conditions are harsher in many ways than those experienced by terrestrial animals. Moreover, the process of anaesthetizing and capturing the fish prior to analysis may produce inaccurate results. To solve these problems, we developed wireless biosensor system to monitor the physiological condition of fish (Wu et al., 2015). This system enables artificial stress-free and non-lethal analysis, and allows for reliable real-time monitoring of fish stress. The biosensor comprised Pt–Ir wire as the working electrode and Ag/AgCl paste as the reference electrode. Glucose oxidase was immobilized on the working electrode using glutaraldehyde. We used the eyeball interstitial sclera fluid (EISF) as the in vivo implantation site of the sensor, which component concentration correlates well with that of blood component concentration. In the present study, we investigated stress due to alterations in water chemistry, including dissolved oxygen, pH, and ammonia–nitrogen compounds. Stress perceived from behavioural interactions, including attacking behaviour and visual irritation, was also monitored. Water chemistry alterations induced increases in the glucose concentration (stress) that decreased with removal of the stimulus. For behavioural interactions, stress levels change with avoidance, sensory behaviour and activity. We believe that the proposed biosensor system could be useful for rapid, reliable, and convenient analysis of the fish physiological condition and accurately reflects the stress experienced by fish.

Monitoring Escape and Feeding Behaviours of Cruiser Fish by Inertial and Magnetic Sensors
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0079392
A method was developed and applied for monitoring two types of fast-start locomotion (feeding and escape) of a cruiser fish, Japanese amberjacks *Seriola quinqueradiata* (Noda et al., 2013). A data logger, which incorporated a 3-axis gyroscope, a 3-axis accelerometer and a 3-axis magnetometer, was attached to the five fish. The escape, feeding and routine movements of the fish, which were triggered in tank experiments, were then recorded by the data logger and video cameras. The locomotor variables, calculated based on the high resolution measurements by the data logger (500 Hz), were investigated to accurately detect and classify the types of fast-track behaviour. The results show that fast-start locomotion can be detected with a high precision (0.97) and recall rate (0.96) from the routine movements. Two types of fast-start movements were classified with high accuracy (0.84). Accuracy was greater if the data were obtained from the data logger, which combined an accelerometer, a gyroscope and a magnetometer, than if only an accelerometer (0.80) or a gyroscope (0.66) was used.

Wireless Biosensor System for Real-Time L-Lactic Acid Monitoring in Fish
https://www.mdpi.com/1424-8220/12/5/6269
We have developed a wireless biosensor system to continuously monitor L-lactic acid concentrations in fish (Hibi et al., 2012). The blood L-lactic acid level of fish is a barometer of stress. The biosensor comprised Pt-Ir wire (ϕ0.178 mm) as the working electrode and Ag/AgCl paste as the reference electrode. Lactate oxidase was immobilized on the working electrode using glutaraldehyde. The sensor calibration was linear and good correlated with L-lactic acid levels (R = 0.9959) in the range of 0.04 to 6.0 mg·dL−1. We used the eyeball interstitial sclera fluid (EISF) as the site of sensor implantation. The blood L-lactic acid levels correlated closely with the EISF L-lactic acid levels in the

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range of 3 to 13 mg·dL−1 (R = 0.8173, n = 26). Wireless monitoring of L-lactic acid was performed using the sensor system in free-swimming fish in an aquarium. The sensor response was stable for over 60 h. Thus, our biosensor provided a rapid and convenient method for real-time monitoring of L-lactic acid levels in fish.

Wireless enzyme sensor system for real-time monitoring of blood glucose levels in fish
https://www.sciencedirect.com/science/article/pii/S0956566308004764?via%3Dihub
Periodic checks of fish health and the rapid detection of abnormalities are thus necessary at fish farms. Several studies indicate that blood glucose levels closely correlate to stress levels in fish and represent the state of respiratory or nutritional disturbance. We prepared a wireless enzyme sensor system to determine blood glucose levels in fish (Endo et al., 2009). It can be rapidly and conveniently monitored using the newly developed needle-type enzyme sensor, consisting of a Pt–Ir wire, Ag/AgCl paste, and glucose oxidase. To prevent the effects of interfering anionic species, such as uric acid and ascorbic acid, on the sensor response, the Pt–Ir electrode was coated with Nafion, and then glucose oxidase was immobilized on the coated electrode. The calibration curve of the glucose concentration was linear, from 0.18 to 144 mg/dl, and the detection limit was 0.18 mg/dl. The sensor was used to wirelessly monitor fish glucose levels. The sensor-calibrated glucose levels and actual blood glucose levels were in excellent agreement. The fluid of the inner sclera of the fish eyeball (EISF) was a suitable site for sensor implantation to obtain glucose sample. There was a close correlation between glucose concentrations in the EISF and those in the blood. Glucose concentrations in fish blood could be monitored in free-swimming fish in an aquarium for 3 days.

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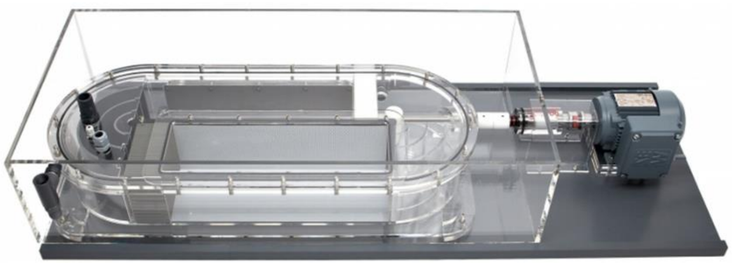
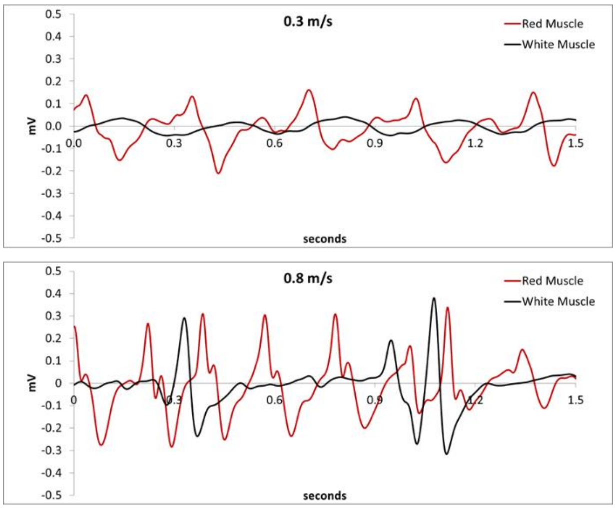
Swimming performances and energetic expenditure

The bioenergetics of the target species (muscular activity patterns) can be modelled, based on fish mass and swimming speed, to predict i) the mass-specific standard metabolic rate (SMR), ii) the active metabolic rate (AMR) and iii) the scope for activity (SFA). The numerical difference between AMR and SMR indicates the energetic expenditure available to support all locomotor and physiological activities (SFA). The oxygen consumption rate (MO_2) can be measured during exhaustive swimming trials (U_{crit}), carried out in swimming chambers (https://www.loligosystems.com/swim-tunnel-respirometer-3), to estimate the energetic expenditure linked to the different swimming velocities. MO_2 can be further calibrated, during the U_{crit} tests carried out in the swimming chamber, with the signals transmitted by the tailbeat accelerometer tags implanted to the fish, as well as with the Electromyograms (EMGs) signal received *via* two pairs of wire electrodes surgically implanted in both the red and white muscle (Zupa et al., 2015). The calibration gives the possibility to correlate each single swimming level of the fish, recorded during the production cycle, to the oxygen consumption rate and, in turn, to a suite of activity indexes expressed as the EMGs levels and tail beat levels. The best models fitting MO_2 as function of the tailbeat and EMGs signals allow estimating, at any muscle activity level, the respective energy cost, recognizing more accurately a stress-related response (McFarlane et al., 2004; Chandroo et al., 2005; Carbonara et al., 2014). In this way, the activity based energetic expenditure can be assessed and, consequently, the fish physiological status too, as well as the relative cost of living for fish in their environment.





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Environmental monitoring

AKVA group have developed a wireless communications network to send water quality and environmental data between pens and barge (https://www.akvagroup.com/pen-based-aquaculture/camera-sensors/enviro-sensors-/environmental-sensor-system).

It is a scalable system, from a single cage installation up to an entire farm cage setup (up to three sensors connected to each cage side unit). The available sensor options are: Oxygen, Salinity, pH, Temperature, TDS, Turbidity, Chlorophyll, and Blue Green Algae. All data can be viewed, recorded and logged within the AKVA connect software package, allowing parameter thresholds to bet set and highlighted. The Akvasmart Enviro Sensor Network is designed as a standalone system, therefore does not require existing camera systems to function. However, when combined with Akvasmart Camera system it centralises your camera and sensor data in an easy to use software environment.

Realtime Aquaculture (http://rtaqua.com/) provides an end-to-end solution for farm environmental monitoring, including a cloud platform and innovative sensors that communicate wireless underwater. This technology enables data-driven ocean farming where knowledge drives better decisions. AquaMeasure is a family of compact, submersible environmental sensors with underwater and in air wireless communications. AquaMeasure wireless sensors are available in three different sensors configurations including Salinity, Dissolved Oxygen, and a Cyclops-7 compatible POD (Blue Green Algae, CDOM/FDOM, Chlorophyll, Turbidity). All AquaMeasure sensors also measure temperature and tilt. The AquaHub is the core of the system deployed in the field and it detects underwater communication from nearby sensors. The hub supports many telemetry protocols for cloud communications including Cellular, Wi-Fi and Iridium. The wireless hub also supports third-party sensors, like weather stations, via its auxiliary sensor port.

Design and Deployment of Low-Cost Sensors for Monitoring the Water Quality and Fish Behaviour in Aquaculture Tanks during the Feeding Process
https://www.mdpi.com/1424-8220/18/3/750/htm
The monitoring of farming processes can optimize the use of resources and improve its sustainability and profitability. In fish farms, the water quality, tank environment, and fish behaviour must be monitored. Wireless sensor networks (WSNs) are a promising option to perform this monitoring. Nevertheless, its high cost is slowing the expansion of its use. In this paper, we propose a set of sensors for monitoring the water quality and fish behaviour in aquaculture tanks during the feeding

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process (Parra et al., 2018). The WSN is based on physical sensors, composed of simple electronic components. The system proposed can monitor water quality parameters, tank status, the feed falling and fish swimming depth and velocity. In addition, the system includes a smart algorithm to reduce the energy waste when sending the information from the node to the database. The system is composed of three nodes in each tank that send the information though the local area network to a database on the Internet and a smart algorithm that detects abnormal values and sends alarms when they happen. All the sensors are designed, calibrated, and deployed to ensure its suitability. The greatest efforts have been accomplished with the fish presence sensor.

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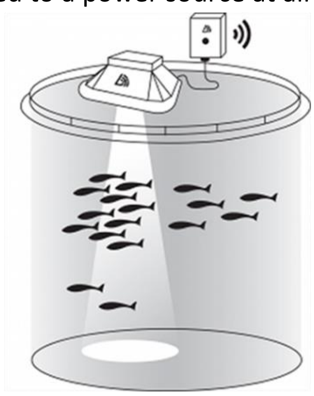
Biomass assessing

Acoustic technology

Acoustic communication is one of the main communication technologies used in underwater environments, due to the ease of sound wave propagation in liquids. Fish detection and size measurement using acoustic signals has been used in research to measure fish size of free swimming or farmed fish. Using acoustic sensors to measure fish sizes accurately, is severely limited due to how inaccurate these measurements inherently are. We present a few commercially products using an acoustic system for fish counting and size measurement below:

The **Sound Metrics DIDSON 300 m** (http://www.soundmetrics.com/Products/DIDSON-Sonars/DIDSON-300m) is a dual frequency, high resolution sonar capable of imaging targets up to 30 meters away. It is primarily used to study the behaviour of fish even in opaque waters, but the clarity of its image alone is normally not enough to allow for measuring fish size accurately for biomass estimation. However, there is research that uses one these devices to measure fish size and also their count while being transferred from one cage to another while minimizing the margin of error. This implementation aims to first stabilize the constantly moving background by ways of a "phase-only correlation method" and then subtract it from the image altogether. Edge tracing is then performed on the fish to obtain segmented images and a Kalman filter algorithm is used to predict their movement to avoid re-counting the same ones. Finally, a search is performed in the separated images of fish and their body length is obtained by summing the segments of the centerline from head to tail (Han et al., 2009).

The **Biosonics Aquaculture Biomass Monitor** (https://www.biosonicsinc.com/products/aquaculture-biomass-monitor/) is a buoy mounted split beam sonar system to ensure no possibility of interference with the fish in the cage. It is externally powered, tethered to a power source at all times and so it can run continuously. With the help of the accompanying software, the process of gathering, storing and analysing the data is fully automated so it is, in that sense, a fire and forget system requiring no manpower once deployed.

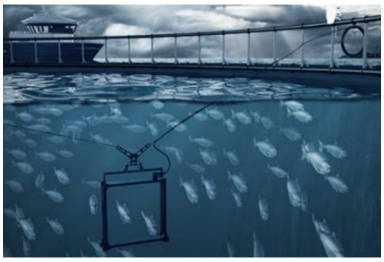


Its output consists of several types of real-time and daily reports including a daily average fish size and also size distribution to aid in making more accurate estimates for projected asset value or gauge feeding effectiveness. A real-time vertical distribution of fish densities report also provides valuable information on the behaviours of the fish so that they can be further looked into to find the underlying causes if required. One of the more important reports provides warnings for escapement and behavioural changes to enable rapid responses towards preventing escapes. Finally, a report detailing every separate measurement taken for that day, such as time, depth, fish size and swim speed can be generated allowing for the application of different analysis techniques as required aside from those the software already provides.

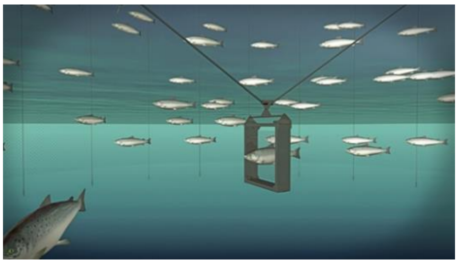
Infrared beams technology

Infrared radiation (IR), sometimes called infrared light, is electromagnetic radiation (EMR) with longer wavelengths than those of visible light and therefore is generally invisible to the human eye. Infrared beam technology has been utilized in aquaculture to detect the presence of fish and biomass estimation. The detection is carried out with the use of Infrared (IR) break-beam sensors. The concept utilizes an IR emitter on one side that sends out a beam of IR light and an IR receiver on the opposite side that is sensitive to that same light. When something that is not transparent to IR light, such as fish, passes between the two then the beam is interrupted, and the receiver will register the appropriate event.

Double curtain IR frames utilize the aforementioned IR beams technology to implement a fish counting and biomass estimation algorithms. The curtains are hanged in fish cages using simple, robust suspension systems. Fish voluntarily swim through them and interrupt a set of infrared light beams; their silhouettes are generated, and their sizes are calculated. However, it is unknown whether the frame influences the sample of fish swimming through it, thereby introducing a bias into the biomass estimation (Zion, 2012). The commercial solutions are:



“Biomass Measurement Frame” (VARD)



“VAKI Biomass Daily” (PENTAIR)

Stereoscopic imaging technology

Underwater stereo-video systems are capable of making accurate, precise, non-invasive measurements of fish length by analysing the pair of simultaneously captured images. Stereo image analysis requires two images of an object from different viewing angles and matching a point in one of the images to a corresponding on in the other. The 2D coordinates of that point can then be used to estimate its 3D coordinates. Therefore, making 3D measurements comes down to accurately identifying and matching pairs of points between the two 2D images (Ruff et al., 1995). In the only commercial solution available, a human operator manually locates the feature of interest (in this case, the snout and tail of the target).
Several factors can affect the accuracy of these measurements in a stereo-video system. External factors such as visibility (opaque water) and lighting conditions but also factors pertaining to the way the system itself was designed. A larger distance between the two cameras allows for measuring targets that are farther away from the system but reducing its ability to measure targets that are close.

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To make accurate measurements the stereo-video system must also be calibrated. There are two prevalent calibration techniques. In one, a 3D object is used to calculate the system's parameters using a photogrammetric network. In the other a 2D object with a checkered pattern is used instead. The central issue for the geometric and statistical strength of the calibration network as a whole is that every single image of a 2D object is fundamentally weaker than a single image of a 3D object, especially if camera calibration parameters are included in the network solution. Any weakness in the network has the potential to increase correlations between individual camera calibration parameters, or between camera calibration and photo orientation parameters. These correlations can result in unpredictable variations in the camera calibration parameters, which can affect the accuracy of measurement estimates. However, the 2D technique is by far easier to use with an openly available MATLAB toolbox (Boutros et al., 2015). The effects of target rotation on the accuracy of the measurements have been tested and it has been found that rotations of up to 50 degrees had very little effect (Harvey & Shortis, 1995).

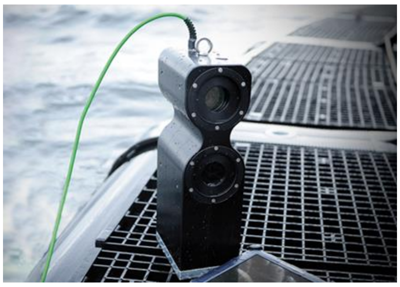
Optimal measurements are recorded when the body of the target is approximately parallel to the focal planes of the stereo pair of cameras (Harvey et al., 2003).

Future developments in the stereoscopic imaging systems include semi and fully automated systems that can facilitate the target selection process. Thus, limiting the need for human interaction for data analysis and acquisition.

Costa et al. (2006) developed an algorithm to extract fish outlines from images and another to reconstruct the 3D coordinates of relevant landmarks based on the extracted 2D coordinates. Additionally, an empirical algorithm, based on an Artificial Neural Network, was used to correct the coordinates obtained from the reconstruction as errors will often occur in real world applications. In another study (Costa et al. 2009) an Artificial Neural Network was again used in a semi-automatic approach to analyse the stereo-images aiming to maintain the high accuracy of a completely manual approach while significantly reducing the required man-hours.

In a more recent paper (Pérez et al., 2018) the captured images are corrected by means of a "Gaussian Mixture-based Background / Foreground Segmentation Algorithm" while at the same time fish silhouettes are located. When the targets have been located, a search is made for the image's regions of interest and their length and height is defined. In a final step, the regions are corrected to account for the target's orientation.

One commercial system that uses a stereoscopic camera system is the **Vicass HD Stereoscopic camera system (AKVA group)**. (https://www.akvagroup.com/pen-based-aquaculture/camera-sensors/camera-systems-/biomass-estimator)



The camera is placed in a waterproof housing and is powered through a cable. The stereo camera imaging is transmitted over a wire and the accompanying software processes the images and outputs results that are used for biomass estimation. The system's placement is dependent on its configured measurement range. Ideally fish should be swimming by it at that range and as close to parallel as possible to the focal planes of the cameras.

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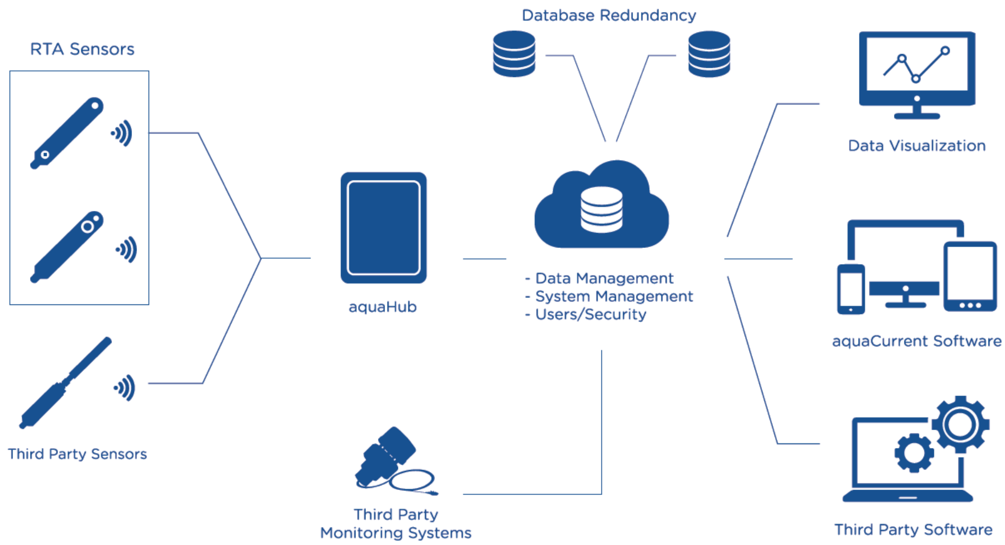
A real-time wireless communication system and sensor network for the large scale demonstration activities

The real time wireless communication system and sensor network envisaged for the FutureEUAqua large scale demonstration activities, including a cloud platform that communicate wireless underwater, will take into account the technology offered by Real-time aquaculture (www.rtaqua.com). This technology enables data-driven ocean farming where knowledge drives better decisions. The system architecture is reported below:



The system include "AquaMeasure" which is a family of compact, submersible environmental sensors with underwater and in air wireless communications. While the "AquaHub" is the core of the system deployed in the field and it detects underwater communication from nearby sensors. The hub supports many telemetry protocols for cloud communications, including Cellular, Wi-Fi and Iridium. The wireless hub also supports third-party sensors, like weather stations, via its auxiliary sensor port.

The **AquaMeasure DO** is a compact, wireless underwater sensor that measures dissolved oxygen (DO), temperature and tilt in real time. DO is one of the most important indicators of the aquatic ecosystem health. In aquaculture, DO measurements are crucially important in optimizing feeding and maintaining healthy fish. DO levels can be affected by numerous variables, such as size of fish, net fouling, water temperature, salinity and atmospheric pressure. Levels continuously vary throughout a day, so it is crucial that aquaculture farmers measure DO in real time.

The **AquaMeasure SAL** is a compact, wireless underwater sensor that measures salinity (SAL), temperature and tilt in real time. Salinity is an important measure of water quality as many species of fish have different *preferendum* of salinity. Although changes in salinity are uncommon, greater fluctuations are found in areas affected by tidal forces or near a freshwater source. Salinity is also used to convert DO saturation measurements into mg/L.

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The **AquaMeasure Turbidity** is a compact, wireless underwater sensor that measures turbidity, temperature and tilt in real time. Turbidity is most often a result of suspended particles of solid matter in marine environments. Indeed, if water is turbid it appears "cloudy" and increased levels of turbidity raise water temperatures, which can be harmful to biomass and affect fish feeding behaviour and welfare. Warm water holds less dissolved oxygen than cold, as less light can infiltrate waters with greater turbidity. Sudden changes in turbidity can also be an indication that a new pollutant source is under development, or entered the water. Real time monitoring of turbidity helps ensure that nothing goes unnoticed and can provide greater insights for other parameters.

AquaCurrent is a cloud-based platform that allows to view and analyse data from the aquaculture sites in real time. The software provides a set of continuously evolving analytics tools that allow to easily view data, from an intuitive and easy to understand web portal, in a number of format. Notifications and alerts allow to receive crucial updates in real time, allowing for a quick passage back to AquaCurrent to view the whole picture. This intelligent notification system is made possible by leveraging an IFTTT approach that allows for high levels of user customization. AquaCurrent works to keep data secure, safe and available. Starting at the dashboard, data is locally stored and then sent to a redundant and backed-up AWS database.

AquaHub is the core of the system deployed in the field and can be easily mounted to existing aquaculture infrastructure or feed barges. Utilizing a digital receiver, communications modem and state of the art electronics, the AquaHub can support up to 100 AquaMeasure sensors within a 500m radius. The AquaHub also support the detection of signals from the family of **VEMCO transmitters**. Namely the V9AP & V13AP accelerometer pressure tags, which measure the fish activity, including swimming speed via tail beat acceleration, mortality through predation, seismic blasting, toxic spills, feeding events, spawning activity, nocturnal/diurnal activity, wave action and activity responses to changing oxygen, salinity and temperature in the rearing environment. The AquaHub supports many telemetry protocols for cloud communications, including Cellular, Wi-Fi and Iridium. It is designed in a rugged, waterproof housing, that stands up to the rough, open water conditions of remote locations. The hub also supports third party sensors (e.g. weather stations, biomass monitoring, etc.) via its auxiliary sensor port and features internal memory for backup purposes.

The system that will measure and **estimate biomass** in the fish-farm cages, must be designed and developed. The envisioned system must provide accurate results in a reliable manner but in a way that it will not affect the fish, or interfere with their daily routine, thus, minimizing the installation difficulties. The system must be able, after the appropriate calibration, to estimate biomass for different kinds of fish (sea-bass, sea-bream, amberjack etc.).

Technology-wise the system must utilize the strong aspects of the aforementioned state-of-the-art systems and try to minimize the need for human presence or interference. It must provide automatic and periodic data to the users/experimenters. We will evaluate the possibility of fusing certain techniques to increase the accuracy of the system and provide consistent results. Software algorithms proposed in research papers will be evaluated and will be applied to test the accuracy of the estimation and try to eliminate any errors that will be the result of hardware limitations.

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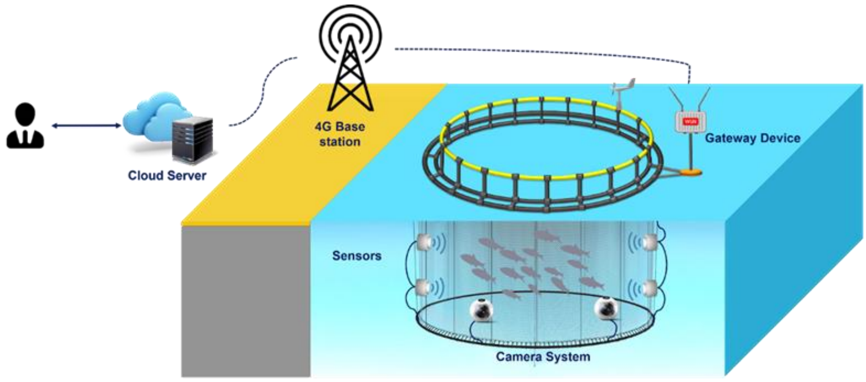
The data will be transmitted through a wire on a gateway device place on the surface of the cage and will be sent over the internet (4G connection) to a cloud server that will process the data and store the results.

The envisioned end-to-end system architecture is illustrated in the image below:



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