Low-cost IoT solutions for fish farmers in Africa

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Abstract: Although fish farming in Africa is developing in the last decade, it still has a big potential of growth to meet the fish demand with growing population. One of the key parameters for a successful fish farm business is the water quality monitoring. Even though it is essential, it is often too expensive for African fish farmers to monitor their ponds. In the WAZIUP project, we deployed a low-cost and connected water monitoring system measuring pH, dissolved oxygen and temperature in a fish farm in Ghana. It has been collecting data since February 2017 and we present here the first conclusions of the water analysis and the impact it could have on fish farming. Based on these results, we aim to deploy several improved V2 prototypes in early 2018.

Keywords: ICT, Water Monitoring, Fish Farming, LoRa, Low-cost, Africa

1. Introduction

1.1 – The aquaculture trend in Africa

In the last decades, aquaculture exponentially grown in the world, especially in Asian developing countries that produce 89% of the total fish production [1]. In Africa, fish farming was first introduced 50 years ago but has experienced many difficulties as explained in [2]. Initial high interest in the innovation of fish farming rapidly dropped during the 1960s as over-expectations were not met and many enterprises were abandoned. It was only in the 1990s, with numerous fish farming development projects that it started again to develop, with a 60% growth in 10 years. Now, fish production from farming in African countries has reached 2.5% of the global fish production.

However, the production is not sufficient to meet the total fish consumption, and many countries still need to import fish every year. In Ghana for example, the combination of the annual supply of fish from capture and from aquaculture does not meet half of the country demand [3]. This shortage in supply is expected to increase further with limited prospects for increasing marine and inland fisheries. Aquaculture has thus become pivotal in the future development of the fisheries sector in Ghana and all African countries in general.

A big potential for increased aquaculture production in Africa exists and is yet to be fully realised. Too often, one of the biggest problem is the lack of information. In Senegal, an initiative from the National Aquaculture Agency is giving opportunities to local farmers to learn how to manage their own fish farm and expect proper fish production yields.

In the Gaston Berger University (UGB) in Saint-Louis, Senegal, a large agricultural farm has been installed whose objective is to set up training and research in both agricultural and agri-food production activities to accomplish and consolidate the university's mission of development in Senegal and the Sahel area. In the activities of this agricultural farm, an aquaculture project allows students to carry out practical work, to popularize actions and activities in the direction of enhancing the value of aquaculture and collect and process statistical data. There are fish ponds on this farm for storage, growing or hatchery.

1.2 – The importance of the water quality monitoring

The fisheries management relies totally on the water quality monitoring. Fish diseases are very frequent and impact directly the harvesting yield [4]. A low water quality can also impact the fish growth and delay the harvest. The optimum fish production is totally dependent on the physical, chemical and biological qualities of water [5] no matter the type of facility. Therefore, water quality is the key to succeed a good fishery management. It is determined by variables such as temperature, turbidity, carbon dioxide, pH, alkalinity, ammonia, nitrite, nitrate, etc. Amongst them, the most critical are temperature, dissolved oxygen and pH.

Optimum temperature is dependent of the fish species, but as fish are cold blooded animals, it is vital that the temperature is controlled and maintained in the correct range. And even in the correct range, higher temperature increases the rate of bio-chemical activity of the microbiota and so increase the oxygen demand. To limit disease and oxygen consumption, temperature has to be finely regulated.

Optimum dissolved oxygen should always be above 5 ppm. Fish needs enough oxygen in the water to survive, otherwise they stay at the surface to catch up more oxygen, have slower metabolism and grow slower, and ultimately can die of lack of oxygen. It is even a bigger problem for aquatic organism to obtain sufficient oxygen than for terrestrial ones, due to low solubility of oxygen in water.

Optimum pH for fish life is between 7 and 8.5, ideal for biological productivity, otherwise fishes can become stressed in water, again slowing down their growth.

Many other parameters may be also monitored, but they generally directly influence the 3 main parameters mentioned above. Monitoring and controling these parameters are therefore the basis for a good water quality. In addition, real-time monitor will provide faster reaction time.

1.3 – Deployment of a prototype in the context of WAZIUP project

On February 1st 2016, a 3-years EU project called WAZIUP (www.waziup.eu) was funded under the EU H2020 programme within the specific topic of cooperation between EU and sub-Saharan countries. WAZIUP is a collaborative research project using cutting edge technological research applications on IoT and related big data management and advanced analytic issues. It aims to provide ICT solutions, (at the lowest price possible, low energy consumption and long-range communication), corresponding to real African rural or urban use cases in order to allow them to reproduce them in a do-it-yourself philosophy.

Amongst all the project's use cases, one of them is to help fish farmers to improve their yield of fish production. A low-cost water-monitoring system has therefore been developed and deployed in fish ponds in Ghana to measure the water quality and give some first advices to the farmers.

2. Objectives

We chose to use a Minimum Viable Product approach to deploy as quickly as possible a simple and operational product and improve the next versions by iterations based on users feedbacks and real needs. The first prototype we deployed is located in Kumah Farms, in Kumasi, Ghana. The objectives are to :

- *Give access to water quality measurements at low cost*

Most fish farmers in Ghana do not have the budget to invest into commercial water measurements sensors. They can only know what action to take on their pond with empirical methods. We wanted to give them the opportunity to monitor their water quality in real-time and at a low cost in order to react more quickly and more efficiently on water quality to improve their fish yield.

- *Test the robustness of the prototype in African weather conditions*

The first deployment of the prototype in Ghana is the starting point to test its robustness in the harsh Africa weather condition: direct sun on the system as well as high humidity level in the rainy season can definitely damage the electronical.

- *Gather data on the fish pond*

The first deployment is also the opportunity to gather the first set of water quality data on a pond and see exactly what the conditions of the water are. It will be used later for comparison with other ponds and conditions.

- *Test the deployment of low-cost gateway with poor internet connection:*

One of the requirement of the gateway is that is has to function despite many Internet disconnections. On rural African situation, Internet connectivity is very unstable and the gateway has to continue to gather the data every time connectivity is down and send all stored data when connectivity is up again.

3. Methodology

3.1 – The prototype assembly and deployment

Figure 1: Assembling of the device part on site. (a) Electronic parts in a sealed waterproof box. (b) Sensors along a tube. (c) Solar panel on the top of the device.

On January 2017, we deployed the device on Kumah Farms, in Kumasi, Ghana. This farm has 18 ponds of various size, from 120m^2 to 0.8 hectares. They grow Tilapia and Catfish, which has a life cycle of 6-8 months before being harvested. After designing the prototype and assembling the electronic parts in France, the prototype was finally assembled on site with help of African local partners and potential final users as illustrated in Figure 1.

3.2 – Gateway deployment

A low-cost gateway was installed at the entry of the farm with a 3G USB dongle (see Figure 2). The distance from the pond to the gateway is about 200m with many obstructions: vegetations, other buildings.

Figure 2: Deployed gateway in the office of Kumah Farms, 300m far away from the device

3.3 – Data analyses

Data was pushed to Elasticsearch™ and visualised in Kibana™ on the WAZIUP data platform. Elasticsearch is a search-engine to realize adequate data aggregations as they are pushed in real-time.

4. Technology Description

4.1 – The prototype based on low-cost sensors

WAZIUP fully takes the "Arduino" philosophy for low-cost, simple-to-program yet efficient hardware platforms. These features are clearly important issues to take into account in the context of developing countries, with the additional benefit that due to their success, they can be acquired and purchased quite easily world-wide.

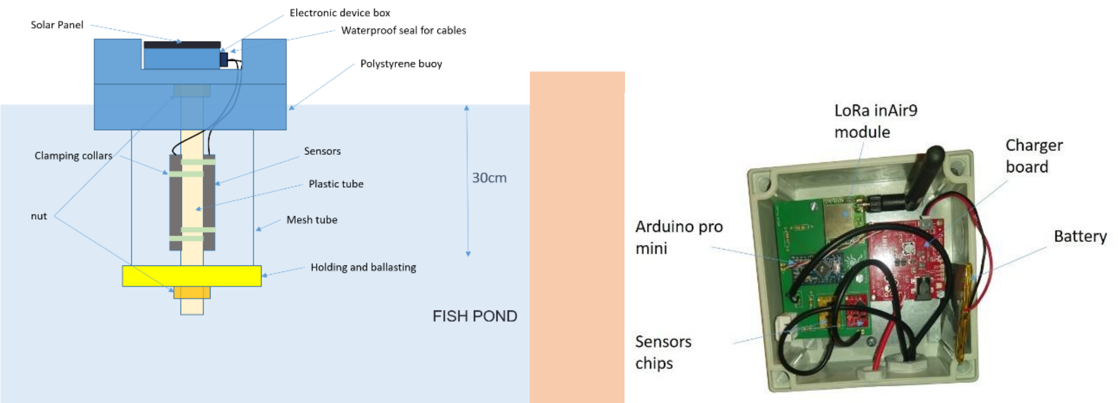

Figure 3: (a) Schema of the first deployed prototype for aquaculture water monitoring in WAZIUP project. (b) The electronic parts in the waterproof case

There are various board types that can be used depending on the application and the deployment constraints and we support most of them. However, the Arduino Pro Mini, which comes in a small form factor and is available in a 3.3v and 8MHz version for lower power consumption, appears to be the development board of choice to provide a generic IoT platform. It can be purchased for less than 2 euro a piece from Chinese manufacturers. We therefore used the Arduino Pro Mini to build the first prototype for the fish farming use case with dissolved oxygen, pH and temperature sensors as illustrated in Figure 3.

4.2 – The low-cost gateway

Along with the prototype, we deployed a gateway in Kumah Farms, Kumasi, Ghana (see Figure 2). In the context of the WAZIUP project, it is important to keep both the cost and the complexity of the gateway low, targeting small to medium size deployment scenarios for specific use cases. The low-cost LoRa gateway listen on a unique frequency channel and runs on a Raspberry™ PI. The total cost of the gateway is as low as 45 euro with the radio module included. However, the WAZIUP gateway has many advantageous features compared to more costly commercial gateways. For instance, a flexible cloud management system allows for data upload to any remote clouds (dedicated IoT clouds such as ThingSpeak, GroveStream, etc.), MQTT brokers, FTP servers, File Sharing platforms (such as DropBox, GoogleDrive, etc.) to name a few. Adding a new cloud platform can be performed in minutes using existing templates. The gateway can also be seen as a Node-Red node to be easily integrated into more complex processing flows. With a 2G/3G dongle, the gateway can also directly send SMS to an end-user or a cloud platform. Sending SMS can be configured to serve as a backup connection. This feature is very useful in WAZIUP as Internet connectivity can be impossible in some areas: SMS are sent to the WAZIUP platform when Internet is not available.

In addition to a versatile remote cloud support, the gateway has a local MongoDB database to store incoming messages. For instance, to handle temporary Internet connectivity issues, the gateway can store received messages until Internet is back again. However, the main utilization for the MongoDB database is to provide easy interaction with an embedded web server to graphically display historical received data on a user's smartphone.

4.2 – The WAZIUP platform

The WAZIUP platform allows developers to process data analysis with cutting-edge tools. Visualisation is available at two levels: it is proposed to users to create simple dashboard to visualise their data in real time, as soon as they are pushed on the platform. To take full advantage of big data analysis features, the users are also proposed to deploy a more complex dashboard with historical or real-time analysis of their data as well as some predictions and decision-making tools. Furthermore, the platform allows to perform data analysis directly on WAZIUP cloud, or to be installed on a local machine, with a manifest to help deploying the analysis. In addition the WAZIUP platform ensures user security by providing identification and roles management, access policy for the platform resources, services for data anonymization and secure transmissions using encryption.

5. Results

Data was sent from the sensors to the gateway and then to the WAZIUP platform for the first time on January 30th, 2017. It worked for 10 days until the first power outage happened. The gateway stores data in case of power lost, so when the power is back, all the stored data will be pushed on the platform, preserving the initial timestamps. After several months of outdoor deployment, the pH sensor is not working properly. This will be taken into consideration for future deployments.

Despite the technical issues, we were able to learn about the general behaviour of the sensors and about their maintenance needs in this first version of the prototype. We also learned about the state of the water of the pond. We took a sample of 10 days from the database, where all the sensors were working correctly, to analyse the water parameters. Even with this short analysis period, we were able to retrieve valuable information about the quality of the water in this particular farm. The results will be summarized and recommendation will be provided to the farmers.

Figure 5 shows all the measured parameters with the deployed prototype. We can see that values are cyclic with clear night and day differences. This is an expected behaviour as sunlight directly affects temperature, dissolved oxygen level and pH level. It also shows that all the parameters are correlated and sometimes, acting on one parameters can affect the others. For example, too high water temperature can lead to saturated oxygen level and sunny afternoons can increase the water pH.

- *Water pH*

In Figure 4, we can see the pH value in the water in early February 2017. The first noticeable feature is that pH variation is cyclical within a day. pH falls at night and reaches its minimum in the morning. Then it rises during the day to reach its maximum at the end of the afternoon. It is normal for pond water to have this kind of behaviour. However, pH variation per day is up to 2.5. This is way too much as it is recommended that pH does not vary more than 0.5 within a day. With the observed range of pH variation, fishes can be shocked, weakened and stop eating. We can also notice that pH is getting too high every afternoon, above the warning level of 8.5 and even above the critical level of 9.

The strong fluctuation of pH during the day combined with high level of pH in the afternoon are symptomatic of a pond with too many algae. Algae and microorganisms use CO2 and can affect the pH of the water and regular balance must be maintained to stabilise the pH. Algae grows and develop quickly when hardness (the amount of CaCO3) of the water is low.

The recommendation in that case is to add dolomite lime (100-200 kg/ha) to increase water hardness and buffering agent [6]. Water should also be changed to stabilise the growth of algae. For sustainability, it is best to closely manage phytoplankton richness by changing the water at least at a rate of one-fifth a day, avoiding overfeeding and using lower fish densities.

- *Water temperature*

We can see in Figure 4 that water temperature is also getting cyclical with natural increase in day and decrease at night. In this pond, the temperature stays most of the time in the recommended range and no particular action is needed for this parameter.

- *Water dissolved oxygen level*

The level of dissolved oxygen is one of the most important factor in aquaculture, as a lack of oxygen can cause fishes to die. In Figure 4, we can see the cyclical behaviour of dissolved oxygen level in the pond. This is an expected behaviour, as during the day with sunlight, algae and microorganisms create oxygen that will be dissolved in water. During the night, as oxygen is not produced anymore, it is consumed by fishes and rapidly decrease until the sun is high enough to allow photosynthesis to take place. In this pond, we can see that all the oxygen coming from photosynthesis during the day is not enough to last all night long for the fishes. Every morning, fishes lack of oxygen that can cause them to grow slow, stress or even die if it last too long. The only way to deal with too low oxygen level in a pond is to aerate the water with manual aerators that brasses water and increase the oxygen level. In this pond configuration, aeration must be done at night to avoid the lack of oxygen in the morning.

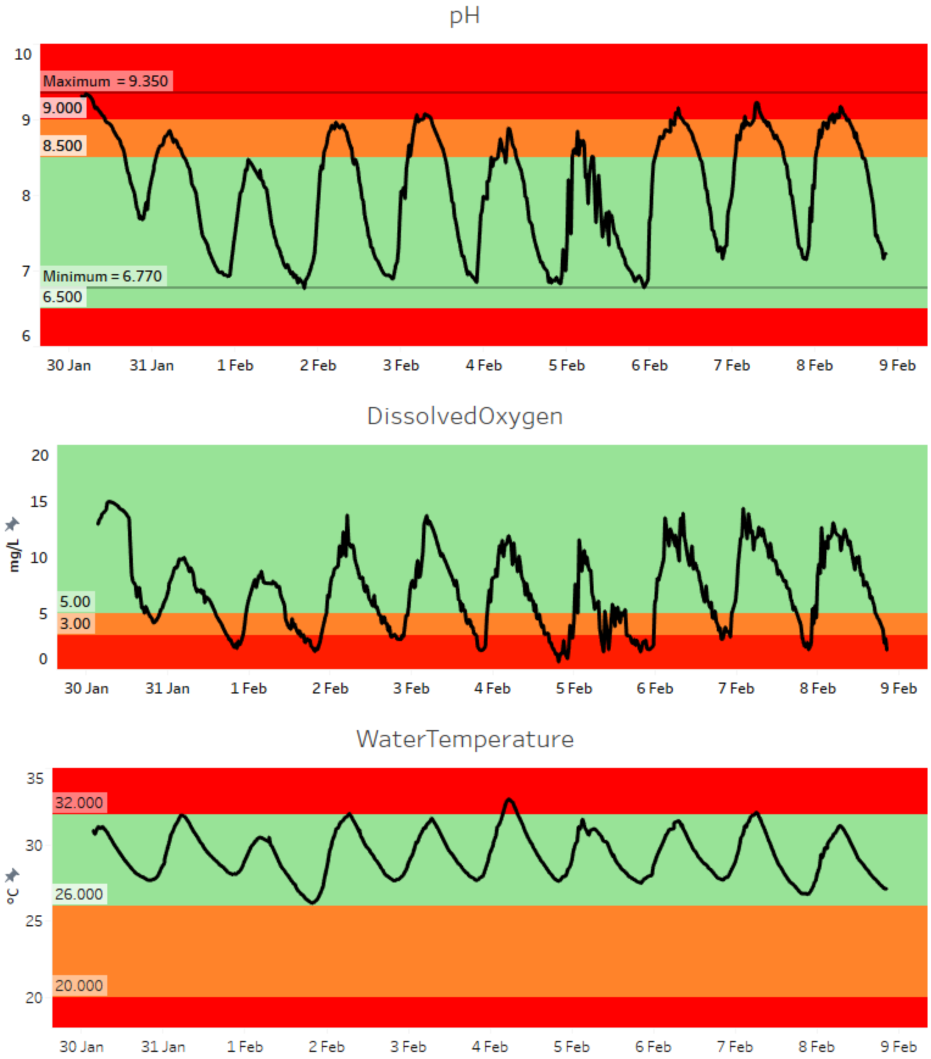

Figure 4: All parameters on 10 days period in beginning of February 2017

6. Business Benefits

With this first deployment in Kumah Farms, we pointed out two major issues in the fish pond: (a) the oxygen level is too low in the morning, that can cause fishes to be stressed and, (b) the pH is too much variating and too high, because of too much algae presence. This can also cause fishes to be stressed. In that case, fishes grow slower, they do not breed and they can eventually die. Our recommendations to improve water quality (i.e. aerate water at night and remove algae with dolomite lime) should considerably improve the fish production yield of this farm.

Although we still need time to let the farmer make the require improvement and to collect the corresponding data, we are confident that it will lead to a significant improvement in the business. Although not comparable in terms of cost, a real-time water monitoring system by Libellium^{TM} in a fish farm in Vietnam [7] showed a reduction of fish losses of about 40 to 50 %. The difference of turnover for each monitored farm in Vietnam is expected to be at least 12,000 USD every 6 months. We expect similar outcome from the low-cost WAZIUP water monitoring system.

7. Conclusions

Deployment of low-cost IoT solutions for fish farmers was made in Ghana, in the frame of WAZIUP H2020 European project. It consisted of a device measuring water temperature, dissolved oxygen level and water pH and transmitting data in real-time by LoRa to a local gateway. Data was then transmitted to WAZIUP platform with 3G internet access. With this first deployment, we learned a lot about the water quality of the pond. We pointed out some recurrent issues in the water quality and gave advices to resolve them. In addition, based on operational feedbacks, we have also built a more robust version of the prototype so we can expect a longer life-time of the device. We are planning to deploy 5 of these new devices in early 2018 in 5 different locations: 3 in Ghana, 1 in Senegal and 1 in Burkina Faso.

We will have a particular use case in Burkina Faso with prediction of the fish growth. Fishing is a very important activity in Burkina Faso carried out mainly by the populations around water reservoirs. Among the major reservoirs where the fishery is developing is the Moussodougou dam, which covers an area of 600 hectares with a capacity of 35,350,000 m3. Since its setting-up, the dam has been the subject of fish farming by indigenous peoples. According to a study carried out by the IUCN (International Union for Conservation of Nature), members of the fishing group have seen their income increase and their living conditions improved since the dam was built.

However, since a while, there has been a decrease in the quantities taken by fishermen, whose causes are certainly multiple. These include anthropogenic pressure (over-exploitation), pollution and climate change. This situation results in a reduction in fish diversity on the one hand and an impoverishment of the actors of the fishing sector with regard to the loss of earnings on the other hand.

Given this situation, stock assessment of various species is becoming a necessity. The overall objective of the planned deployment is to identify the degradation factors of the production and to quantify the specific biomasses exploited in the dam of Moussodougou in order to know the state of their exploitation. In this deployment, in addition to collecting the physicochemical parameters of the water, we will:

- determine biological variables (bio-indicators) from benthic macro-invertebrates and phytoplancton;
- identify and quantify the main species exploited in the dam with machine learning techniques.

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