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IMPAQT Miniaturized Underwater Acoustic Telemetry Platform: Transmitter Node System Design

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***Abstract*—The marine environment and its natural resources are an essential part of the geographical ecosystem and a great food source for humans. In recent years, terrestrial wireless sensor networks and Internet of Things (IoT) technologies have developed rapidly; however, due to the limitation of signal propagation in water, there is less development and advancement in the underwater sensors network domain. IMPAQT is a European research project aiming at the development of the technologies and methods to promote and support inland, coastal zone and offshore Integrated Multi-Trophic Aquaculture (IMTA) sites. As part of the IMPAQT project, a novel underwater acoustic telemetry platform has been proposed and is under development, to provide a method to collect and transmit sensors data underwater. The proposed platform architecture consists of several ultrasonic transmitter sensor nodes and a gateway buoy as a data aggregator interface. Transmitter nodes will collect and log underwater sensor data and transmit it at regular intervals to the gateway buoy and the gateway buoy will send the collected data to a data management system using a Long Range (LoRa) communication link. The IMPAQT Transmitter node has an integrated accelerometer sensor, a temperature sensor, and a pressure sensor onboard. There is also an Infrared Data Association protocol (IrDA) interface that can be used to attach any external auxiliary sensor module to the transmitter node and configure the transmitter node to collect the external module's data. The current version of the transmitter node under development can be attached to seaweed, or it can be used as a floating sensor node in the water and due to its small size and weight design it almost has no impact on the working environment. In this paper, the background of the miniaturized underwater sensors is studied, and design method of the transmitter node is discussed. Future work will focus on the test and deployment of the transmitter and gateway in marine deployments.**

Keywords- Biotelemetry; Underwater communication; Underwater sensors network; underwater sensor node;

I. INTRODUCTION

According to the latest United Nations world population estimation, by the year 2050, the population of the earth will reach approximately 10 billion people [1], and this increase will result in higher demand for food and consequently seafood as it is one of the main source of food and nutrition for many people. In the past, capture fisheries productions were the primary source of the seafood, but this has been changed in 2012, where aquaculture production volumes exceeded that of the capture fisheries, and it is seen to be increasing rapidly in recent years to meet demand [2]. To provide more sustainability, reduce environmental impacts, and promote economic gains, integrated multi-trophic aquaculture (IMTA) is gaining popularity among marine farmers. In IMTA, farmers combine fed species (e.g., fish, shrimp, oysters) with extractive species (e.g., seaweed, mussels), and extractive species will use the by-products of the fed species, reducing the environmental impact of the sites and also to provide commercial profit to the farmers.

IMPAQT is a European project aimed at promoting and supporting the development of IMTA sites by providing a multi-purpose, multi-sensing, and multi-functional data management platform. To provide accurate and relevant information about the underwater environment, a novel miniaturized low-power and low-cost underwater transmitter node and a gateway buoy receiver have been proposed and is being evaluated to collect information from sensors and transmit it to the inland data aggregators. The transmitter node has integrated onboard sensors, and it is capable of interfacing with external sensor modules using the optical IrDA protocol.

The IMPAQT underwater telemetry platform is an ongoing project, and currently, various design parameters and solutions are under evaluation and development.

In section II, the current state of the related research projects studied. Section III describes the development of the transmitter node circuit, design parameters and, also power analysis of the circuit. Section IV addresses the current state of the project and plans for improvements.

II. BACKGROUND AND RELATED WORK

With the rapidly increasing and evolving aquaculture market sector, it is essential to monitor and analyze the effects of the methods that have been used in aquaculture, to reduce the costs and improve stability and sustainability of the sites. There is experimental monitoring in the labs and tanks. However, due to the differences between the experimental environment and real aquaculture environments, it is hard to compare accurately, especially when it comes to the biasing

caused by the handling of marine animals [3]. In [4], authors proposed the concept of Precision Fish Farming intending to use scientific methods to manage the fish production by enabling farmers to monitor, control and document the biological process in fish farms. With the advancement of chemistry and electrical sensing technologies, it is now possible to develop miniaturized attached sensor devices to track and study the natural behaviour of marine animals and plants in their cultural environment.

To achieve the goal mentioned earlier, in [5], authors describe the development of an ultra-low-power sensor device, AE-FishBIT, for monitoring physical activities and respiratory frequency of the farmed fish, using the onboard accelerometer sensor, attached to the fish, and logging the sensors' information. *AE-FishBIT* is not able to transmit the data, and the fish is required to be captured to download the sensors data, however, due to its form factor and size, it is easy to attach and detach the device to the operculum of the fish. Almeida et al. [6] monitored the behaviour of Lusitanian toadfish using accelerometry data provided by the externally attached *AccelTag*, which was able to log, recognize and transmit behaviour type of the fish.

There are also devices for tracking the movement of the fish in dams, fisheries, and cages, shown in Figure 1. In [7], authors have developed the Juvenile Salmon Acoustic Telemetry System (*JSATS*), to identify and track the movement of juvenile salmon in dams and rivers. *JSATS* tags are extremely compact, with a length of 15mm and a diameter of 3.38mm, which allows them to be injected using a needle into the body of the fish. They can transmit ultrasonic pings for a year with a 15-second ping interval. But *JSATS* tags are only capable of transmitting a pre-programmed unique identification code and temperature data, and they are not able to provide any other sensor data.

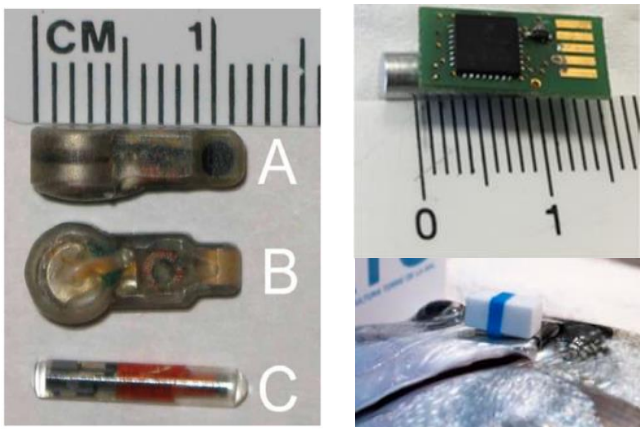
Another method to monitor the marine environment is to use unmanned underwater vehicles. SeaSmart has introduced three patented wireless drones to collect environmental data, for instance, oxygen, salinity, biomass, and temperature, by travelling through the cage to collect data and returning to surface to transmit the collected information. [8].

There are also efforts on monitoring IMTA and aquaculture sites using remote sensing technologies, in [9], authors have used multi-sensor (satellite, unmanned aerial vehicle, and ground spectroradiometer) remote sensing techniques to monitor seaweed aquaculture in the Yellow Sea.

III. MATERIALS AND METHOD

The focus of IMPAQT telemetry project is on IMTA sites, where all sensors will be deployed in a bounded area, and it is considered that the gateway buoy will be in a maximum distance of 100m from each sensor tag.

In Figure 2, the IMPAQT telemetry system is shown, and in this paper, the design method of the transmitter node will be discussed. The goal of the transmitter is to transmit sensors data provided by its internal sensors or externally



A B

Figure 1. (A) JSATS Tags (B) AE-FishBIT tags

connected sensor to the gateway buoy using acoustic waves. The IMPAQT transmitter node needs to be miniaturized to minimize its impact on the deployment environment. Considering the size and power consumption of the tag, accordingly, the block diagram design in Figure 3, and associated system design is suggested. Regarding the receiver aspect of the transceiver system, the buoy mounted gateway board is an application specific system designed in conjunction with the transmitter board described in detail in this publication. It is anticipated that the full transceiver system (gateway and transmitter) and its deployment will be described in full in a follow on publication.

A. *Transducer material selection*

PZT materials are one of the most widely used piezoelectric materials, and they have been used in different applications, in particular as fish tags [6][7][10]. In [11], four types of PZT materials' (Customized Type VI, Type VI, Type I and Type II) energy consumption, source-level, and frequency response has been compared. From the energy consumption aspect, PZT Type VI consume more energy comparing to other types, but they also provide better source level and frequency response compared to others. By comparing the results, type VI had a good balance between the source level and power consumption; consequently, for designing the JSATS tags, they have used PZT Type VI material.

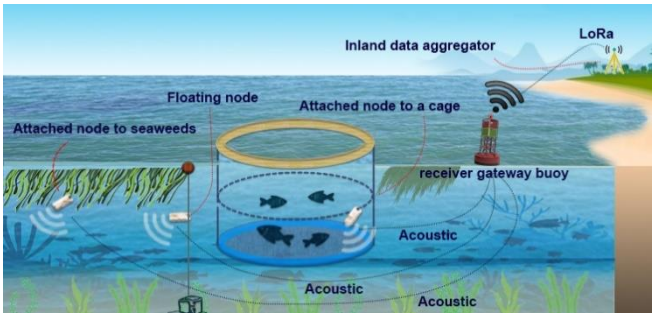


Figure 2. IMPAQT telemetry platform

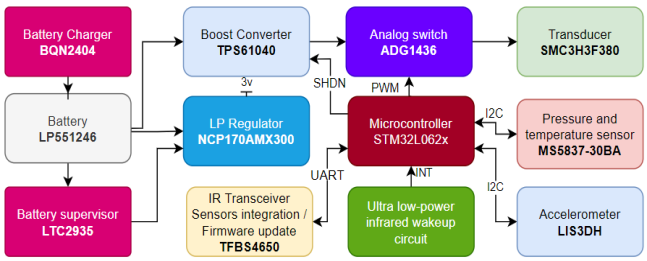


Figure 3. Block diagram of IMPAQT Acoustic Transmitter Node

For IMPAQT transmitter tags, a PZT type VI (*SMC3H3F380)* from *STEMiNC Inc*, with an outer diameter of 3mm and height of 3mm, with the resonance frequency of 380 KHz ± 15KHz has been selected.

B. Transducer driver

To estimate the required driving voltage for the piezo transducer to provide sufficient detection range, it is necessary to study underwater acoustic models and signal absorption loss. The sound emitted by the piezo transducers is attenuated by two main factors, viscous absorption factor, and chemical relaxation effect. The selected piezo material resonance frequency is at 380KHz, and at this frequency, viscous absorption and magnesium sulphate relaxation effect is significant, which can be estimated by the following simplified formula [12] :

$$\alpha = 0.106\frac{f_1 f^2}{f^2+f_1^2}e^{(pH-8)/0.56} +0.52\left(1+\frac{T}{43}\right)\left(\frac{S}{35}\right)\frac{f_2 f^2}{f^2+f_2^2}e^{-z/6} +0.00049 f^2 e^{-\left(\frac{T}{27}+\frac{Z}{17}\right)} \quad (1)$$

Where in the proposed design and operating environment, f=380KHz (Piezo resonance frequency), T = 8°C (water temperature), S = 35ppt (seawater salinity), pH = 8.1 (current ocean pH level [13]), z = 50m (estimated working depth), and relevant relaxation frequencies are:

$$f_1 = 0.78\left(\frac{S}{35}\right)^{\frac{1}{2}} e^{\frac{T}{26}} \text{ (for boron)}, \quad (2)$$

$$f_2 = 42e^{\frac{T}{17}} \text{ (for magnesium)} . \quad (3)$$

Using (1) by substituting the parameters, the absorption loss of 92.4 dB per kilometer has been estimated for an infinitely narrow acoustic beam, however, practical beams spread as they propagate through the water, in order to mitigate the spreading loss, (4) can be used for the transmission loss at the distance of R [14]:

$$TL = TL_1 + \alpha R, \quad (4)$$

$$TL_1 = 20\log R , \quad (5)$$

In the IMPAQT project, a maximum distance of 100m is considered between the transmitter and receiver nodes, which leads to an overall transmission loss of 49.2 dB at 100m.

To provide an adequate sound level, a voltage booster circuit has been implemented using TPS61040 controller, which can boost the 2.5-3.7v (LiPo cell voltage) up to 28v.

The average current of the piezo transducer can be estimated by (6) [15] :

$$I_{Avg} = \frac{2Q}{T} = 2CVf \quad (6)$$

Where Q = Charge in the piezoelectric transducer, T=Period of the driving signal, C= 70pF (Static capacitance), V = 20v (Driving voltage), F = 380KHz (Resonance frequency). Using the parameters of the selected piezo material, the average current would be about 1mA.

The tag's sound level can be programmed using the IrDA interface based on the use case. ADG1438 analog switch IC has been used to drive the piezo terminals at the boosted voltage using PWM modulation provided by the microcontroller.

C. Sensors and external interface

An accelerometer sensor (LIS3DH), and a pressure and temperature sensor (MS5837-30BA) are included in the IMPAQT transmitter tag to monitor the aquaculture environment and tag movement. TFBS4650 is also selected as the external sensors interface, where auxiliary sensor boards and modules can communicate with the transmitter tag to transmit their sensor value to the gateway buoy, at real-time or at predefined intervals. External sensor modules can also trigger the tag's microcontroller to wake up and read the external sensors data using the low-power infrared wake-up circuit. The evaluation boards and IrDA transceiver have been shown in Figure 4.

D. Power consumption and battery management

The transmitter tag runs on a 260mAh LiPo battery (Part number:LP551246). There is a compact battery charger and a battery supervisor circuit on the board, to charge and cut off the battery in the case of full discharge.

Considering the 260mA battery, total sleep current of 6.34uA (refer to Table I which is based on data available on individual product datasheets), the maximum current of about

TABLE I COMPONENTS POWER CONSUMPTION

Component	Sleep current (µA)	Typical supply current (µA)	Max supply current (µA)
BQ24040	1	1	6
LTC2935	0.5	0.5	0.5
TPS6104	1	25	25
NCP170AMX300	0.5	0.9	0.9
TFBS4650	0.01	75	2000
ADG1436	1	170	280
STM32L062x	0.23	312	780
MS5837-30BA	0.1	20	1250
LIS3DH	2	2	11
Piezo	0	1000	1000

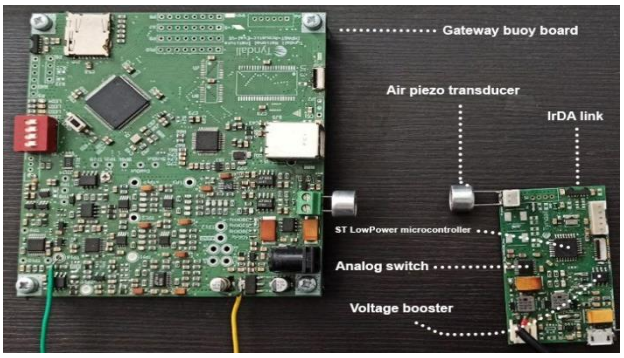


Figure 4. IMPAQT telemetry platform evaluation board

5.3 mA when sampling all sensors, and about 1.6mA while transmitting the data, based on user configuration the battery life can last from two weeks to three months.

To maximize the battery life, the tag can be programmed via IrDA interface to wake up and read the sensors data at regular intervals, while also an external sensor or module can force the tag to wake-up using the wake-up circuit.

IV. Conclusion and Future work

The proposed telemetry method, using a transmitter and a gateway buoy can help farmers and researchers to monitor and analyze underwater water environment. The proposed transmitter tag incorporates an accelerometer, a temperature sensor and a pressure sensor. However, the main novelty of this work is its size and that it is designed to be attachable to other sensors and modules. This project is a work in progress, and it is considered to improve aquaculture sites monitoring as a part of IMPAQT project, which is ongoing.

Currently, the transceiver system prototype boards, shown in Figure 4**,** have been developed and evaluated in air and 200 bit per second achieved using binary phase-shift keying and On-Off keying modulations at 40KHz frequency. It is expected that by using 380KHz piezo materials, the bitrate will increase significantly, which will reduce the overall battery consumption and lead to more frequent data capturing and transmitting. Based on the components that have been selected, it is estimated that the final dimension of the tag would be less than 5 cm x 2 cm x 2 cm. This system will be tested in an aquatic environment and reported on in a subsequent publication.

In future, more studies can be done on the optimization of the battery consumption, bitrate improvement and more miniaturized design. Also, there would be an opportunity to connect the tag to the sensors developed by other colleagues in IMPAQT project to provide a better understanding of underwater environments.

Acknowledgments

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