Evaluation of UAVs as an underwater acoustics sensor deployment platform

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Marine surveys carried out by passive acoustic monitors conventionally use towed hydrophone arrays, which requires dedicated surface observation boats. This is a costly and slow process, which could be made cheaper and quicker by using unmanned aerial vehicles. Presented in this paper are the initial findings from using unmanned aerial vehicles to capture underwater acoustic signals from an acoustic test tank.

1 Introduction

Current methods of performing underwater acoustic environmental surveys, for example detecting marine mammals or making direct sound field measurements, are costly, time consuming and often hazardous. To overcome these problems, an Unmanned Aerial Vehicle (UAV) has been modified, and has being evaluated to determine its viability for carrying out specific missions, including underwater acoustic measurement in the marine environment. This offers potentially lower cost, improved safety and a higher spatial agility than conventional boat-based methods.

Current systems for large-scale aerial surveys utilize fixed wing vehicles (Hodgson *et al*. 2016), due to their speed and range. Use of this technology for relatively short term environmental monitoring at fixed locations is impractical due to their need to move continuously to stay in flight with a flight duration that is still limited.

The alternative proposed here takes the form of a multirotor aircraft and has the capability to hover and to take-off and land vertically. In this study it is envisaged that the UAV would take off from a support vessel or land base, fly to station, land on the water's surface and then deploy underwater sensor packages to carry out acoustic monitoring,. Underwater environmental data would then be collected, recorded and if required, transmitted in real-time to a base station. Due to low power requirements whilst recording, the system could potentially stay on station for significant periods before taking off and returning to base. The versatility of the spatial positioning of the UAV would allow the system to rapidly redeploy, possibly to different locations, multiple times within a single mission. The development of smart systems comprising multiple UAVS in order to complete pre-determined large–scale underwater environmental surveys is envisaged using this technology at a fraction of the cost and risk of current methods.

1.1 Background

Acoustic surveys of the marine environment are now commonly carried out as part of almost all offshore activities. The requirement for these measurements has grown rapidly in recent years in response to growing concerns about the impact of anthropogenic, underwater noise and how it affects different marine animals (Williams *et al.* 2015). Activities such as harbour construction, marine piling for renewables development, Oil & Gas exploration and production, defence, research and many others now regular require noise assessment as part of their Environmental Impact Assessment (‘The Marine Works (Environmental Impact Assessment) Regulations 2007’ 2007).

One example is marine piling; this process releases high levels of acoustic energy into the seabed and water surrounding it (Duncan *et al.* 2010). This acoustic energy has the potential to cause injury, or even death, to marine mammals and fish (Boyd *et al.* 2008) (Dawoud *et al.* 2016). This has led to legislation being developed and enforced by government. The UK is advised by the Joint Nature Conservation Committee (JNCC) on the piling protocols that should be followed (JNCC 2010). These include a 500 m radius exclusion zone around a piling site that must be free from marine mammals for at least 20 minutes prior to piling

These guidelines suggest the use of Marine Mammal Observers (MMOs) and Passive Acoustic Monitors (PAMs). MMOs visually inspect an area of interest for marine mammals, hoping to sight them as they surface for air. PAM operations generally use towed array hydrophones to listen for marine mammal vocalisations. Dedicated surface observation boats are often used to transport the MMOs, PAMs and equipment to the location of interest. The vessels used can be expensive and have relatively slow redeployment rates. The requirement to cover a 500 m radius observation range may mean several such vessels would need to be operated simultaneously. The use of multiple vessels can be cost prohibitive and often a compromise such that the use of a single vessel providing more limited coverage is used.

The use of UAVs to acoustically survey an area of interest has the potential to significantly reduce the cost of conventional methods, by reducing the number of vessels required to fully survey an area, as well as reducing the redeployment times and reducing health and safety exposure for over side deployments. The current rapid growth of the use and technology enhancements of UAV has therefore lead to the current investigation of the novel use of UAV's for underwater PAM operations which have not been previously reported.

2 Methodology

A waterproof quadcopter, known as the Splash drone ('SPLASH DRONE AUTO VERSION' 2016), has been retrofitted with a custom, lightweight acoustic Data Acquisition system (DAQ). It has been tested on the Loughborough University's 81 000 litre 9 m long, 5 m wide, 1.8 m deep acoustics test tank, where it was flown (Figure 1) and landed on the surface of the water (Figure 2). While on the surface of the water the UAV shut off its motors in order to keep the system's self-noise to a minimum. The

DAQ began to record underwater acoustics within the tank from a hydrophone suspended below the UAV. A calibrated test transducer was used to induce signals into the tank at a range of frequencies. The data acquired from the UAV system has been analysed and compared with a conventional hydrophone deployed in the same tank, at the same time, under the same conditions. The transducer was placed 1 m away from both the UAV DAQ system, and the conventional hydrophone. The tank is a reverberant environment meaning the acoustic signals generated will reflected around the tank and onto both of the hydrophone systems making determination of absolute source levels difficult however relative levels observed on both hydrophones are used to demonstrate feasibility of this proof of concept before conducting further trials in a free-field open water site. Data from these initial tests in the Loughborough University test tank are presented in this paper.

Figure 1 - UAV during flight over the test tank.

Figure 2- Showing the UAV on the test tank waters surface

2.1 Equipment

2.1.1 Swellpro Splashdrone

The Splashdrone (or Mariner II) is a fully waterproof UAV, and has the ability to take off and land from the surface of water. The flight controller is the Auto Plus model, and is Swellpro's own, which adds additional functionality over the Pro version, including automatic waypoint flight functionality, enabled via an android app. Without the gimbal attached the Splashdrone can carry an additional 1kg of equipment, with a maximum take-off weight of 2.8 kg, although it is desirable that the weight is kept to a minimum to extend flight and deployment time. It is powered by a 4 cell, 14.4 V, 5200 mAh lithium polymer battery, which provides a flight time of 20 minutes without a payload. The motors have been specially designed for the Splashdrone and are resistant to fresh and salt water. The system can be controlled up to 1 km away via Swellpro's own remote control, although current regulations prohibit operation beyond a maximum of 500 m.

The Splashdrone Auto version has 12 inch carbon fibre propellers, with a 4.3 inch pitch, which help propel it at up to a 21 m s^{-1}, claimed by its manufacturer ('SPLASH DRONE AUTO VERSION' 2016) , allowing it to operate in high wind speeds. Dimensionally, including propellers, the Splashdrone is 500 mm by 500 mm by 120 mm (length, width and height). A waterproof housing measuring 215 mm by 150 mm by 85 mm (length, width and height) is attached to the underside of the Splashdrone which contains the pre-amp, myRIO ('NI myRIO' 2013) and hydrophone connection. The hydrophone is deployed 930 mm below the waterproof housing resulting in the hydrophone being 1 m below the water's surface when the Splashdrone lands on the waters' surface. A scaled image of the whole system can be seen in Figure 3.

Figure 3-Scaled image of the Splashdrone system

2.1.2 Data acquisition system

A small and lightweight (170 g including cable) Brüel & Kjær 8103 passive hydrophone, measuring 50 mm in length and 9.5 mm in diameter, has been selected. It is omnidirectional below 100 kHz (x-y plane and x-z plane), apart from in the direction of the cable. The frequency response is relatively flat between the frequencies of 3 Hz to 61 kHz (+/-3dB), with a sensitivity of -211 dB re 1V μPa^{-1}.

A custom built pre-amplifier is used to boost the signal to a suitable amplitude for the recorder system as well as to improve signal to noise. The amplifier used includes a 2^{nd} order, single stage, band-pass filter with 3 dB bandwidth of around 30 kHz from 9 Hz upwards and a gain of 27 dB over range 100 Hz to 10 kHz. The frequency response of the system is given in a Bode plot (Figure 4). The operational amplifier used is an Analogue Devices AD743, which has a gain bandwidth product of 4.5 MHz at unity gain, resulting in a potential bandwidth of 200 kHz at the gain setting used, although this is limited by the band pass filter on the pre-amplifier.

Figure 4-Bode plot showing frequency response of amplifier used

The data logging is performed by a National Instruments myRIO. It consists of two main parts; the Real Time (RT) side and the FPGA side. The myRIO was programmed using LabVIEW, using both the FPGA and the RT side. The signal from the pre-amp is fed into a 12-bit ADC (Figure 5), which is read by the Xilinx Zynq 7010 FPGA at 125 kS s^{-1}. The data is then written to a FIFO buffer, which is read by the real time dual-core ARM Cortex A9. The ARM Cortex writes the data to a .csv file for future analysis. The whole system is placed inside a waterproof enclosure which is then attached to the underside of the Splashdrone. It is powered by four 3s, 11.1 V, 180mAh lithium polymer batteries in parallel, each weighing 19 g for a total of 100 g including connectors. The myRIO is Wi-Fi enabled, allowing control of the logging of data via a laptop computer.

Figure 5-diagram of the DAQ system

2.1.3 Source Transducer

The source transducer used in the experiment is a Neptune Sonar Limited Model D/17 Spherical projector. Its useful transmit range is from 10 kHz up to 30 kHz, with its resonant frequency occurring at 17 kHz. It is omnidirectional (+/-1 dB) up to 30 kHz.

Its transmit sensitivity varies depending on the frequency that it is emitting. At 10 kHz, it has a sensitivity of 135 dB re 1 μPaV^{-1} re 1 m, which roughly linearly increases up to 148 dB re 1 μPaV^{-1} re 1 m. This then decays back to 135 dB re 1 μPaV^{-1} re 1 m at 30 kHz.

2.1.4 Comparison Hydrophone

The comparison hydrophone system consisted of a Reson 4014 which, between the frequencies of interest, 10 kHz to 30 kHz, limited by the source transducer and the size of the tank, has a flat sensitivity response of -171 dB re 1 $V\mu Pa^{-1}$. This is connected to a Reson A2002 hydrophone amplifier, set to a balanced input, with the high pass filter set to 10 Hz and the low pass filter set to 100 kHz, which covers the whole range of the band pass filter on the UAV system. After initial testing the gain was set to +30 dB. The output of the A2002 amplifier is connected to a National Instruments USB 6251 BNC data logger which logs the data received at a rate of 125 kS s^{-1} to a .WAV file. Data from both hydrophones are pulled into a MATLAB script which performs a Power Spectral Density (PSD).

3 Results and discussion

Results are presented in the form of a PSD, this makes each measurement comparable, while taking into account gain settings, hydrophone sensitivities, and voltage scale range setting, while being normalised through the spectrum of frequencies used, which takes into account the size of the Fast Fourier Transform (FFT) used. This allows a direct comparison between the following results. A PSD with an FFT size of 4096, with a 50% overlap, with a Hamming window applied was used throughout all PSD computations.

3.1 Tonal comparison

Figure 6 contains the response of each hydrophone system, to a source emission of 12 kHz, which are plotted alongside ambient noise levels. As can be seen, the ambient noise level for the UAV (green) contains noise, and on investigation this was found to be electronic in nature. With this in mind both the Reson hydrophone and UAV hydrophone have the same peaks are the frequencies expected. These three peaks occur at 12 kHz, 24 kHz and 36 kHz respectively, with amplitudes of 221, 164 and 161 dB re $\mu\text{Pa}\sqrt{\text{Hz}}^{-1}$ for the UAV and for the Reson the amplitudes are 210, 87 and 91 dB re $\mu\text{Pa}\sqrt{\text{Hz}}^{-1}$. The 12 kHz frequency is the one induced into the tank, and the 24 kHz and 36 kHz are harmonics of the waveform.

Three peaks of interest, which are present in all UAV recordings, occur at around 14.3 kHz, 16.6 kHz and 18.7 kHz respectively. These peaks very in amplitude but on Figure 6 these peaks are at 168, 155 and 163 dB re $\mu\text{Pa}\sqrt{\text{Hz}}^{-1}$, which are of a similar amplitude.

Figure 6- PSD of both hydrophones at a frequency of 12 kHz

Figure 7 contains the response of each hydrophone system to a source emission of 25 kHz, plotted alongside ambient noise levels. The UAV has reduced noise content at this higher frequency. Comparing both hydrophone systems, both contain peaks at 25 kHz and at 50 kHz. The UAV peak at 50 kHz reduces by a higher amount compared to the Reson hydrophone system, due to the band pass filter on the amplifier. The UAV has amplitude of 246 dB re $\mu Pa\sqrt{Hz}^{-1}$ at 25 kHz and 159 dB re $\mu Pa\sqrt{Hz}^{-1}$ at 50 kHz. The Reson has an amplitude of 221 dB re $\mu Pa\sqrt{Hz}^{-1}$ at 25 kHz and 180 dB re $\mu Pa\sqrt{Hz}^{-1}$ at 50 kHz.

Figure 7- PSD of both hydrophones at a frequency of 25 kHz

Figure 8 shows each systems response to lower frequencies. The source transducer was set to emit 4 kHz, which both graphs display, although the second peak at 12 kHz only shows on the Reson plot, same for the third. This is due to baseline dB re $\mu Pa\sqrt{Hz}^{-1}$ being at the amplitude of those emissions. At 12 kHz the Reson amplitude is 107 dB re $\mu Pa\sqrt{Hz}^{-1}$ which is lower than the baseline for the UAV.

Figure 8- PSD of both hydrophones at a frequency of 4 kHz

4 Conclusions

Tests to investigate feasibility of underwater acoustic acquisition from a UAV deployed DAQ and hydrophone have been successfully carried out. Comparison with a conventionally deployed hydrophone to acquire the same underwater acoustic signals in a reverberant test tank over a range of frequencies (4 kHz, 12 kHz and 25 kHz), show comparable signal levels confirming general feasibility of the concept of UAV deployed passive acoustic systems with potential uses in a wide range of applications. Limitations in the UAV system self-noise were observed due to electronic interference. This needs further development through either shielding or filtering. These developments need to be balanced against consequence of added weight to the payload and the UAV as a deployment platform. The current small UAV (less than 3 kg) however has shown the feasibility of carrying and deploying a standalone underwater recording system.

Tests in future will involve visiting free field sites outside of the laboratory where weather will become a limiting factor. The Splashdrone specifications state that it is useable in winds of up to 21 m s^{-1}, although in gusty conditions it may become uncontrollable for either human or autonomous control. The wave height at these wind speeds can reach up to 4 m (Metoffice 2010) if far enough from land, which may result in capsizing of the Splashdrone. To overcome these possible problems it may be advisable to use a larger UAV, with a larger number of propellers, to improve the stability in flight at higher wind speeds, as well as increasing surface area in contact with the surface of the sea, to reduce the chances of capsizing. Alongside these changes, improving shape of the Splashdrone to make it more aerodynamic could also improve stability during flight if it was required.

4.1 Future Work

A retractable hydrophone attached to longer cable is under development in order to deploy at greater depths in the marine environment, as well as improving the safety of the flight. The system will be developed around the existing data logging system, thus providing a water proof housing as well as retractability. The Splashdrone remote will be remapped to provide the capability to remotely turn on and off the data logging without the need for a laptop computer. An alternative open source flight controller such as the Pixhawk, which is based on the PX4 framework (Meier, Honegger, and Pollefeys 2015), will be programmed to provide the functionality of automatic landing and take-off from the water’s surface as well as boat based deployment and retrieval.

5 References

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Figure 1. UAV during flight over the test tank.

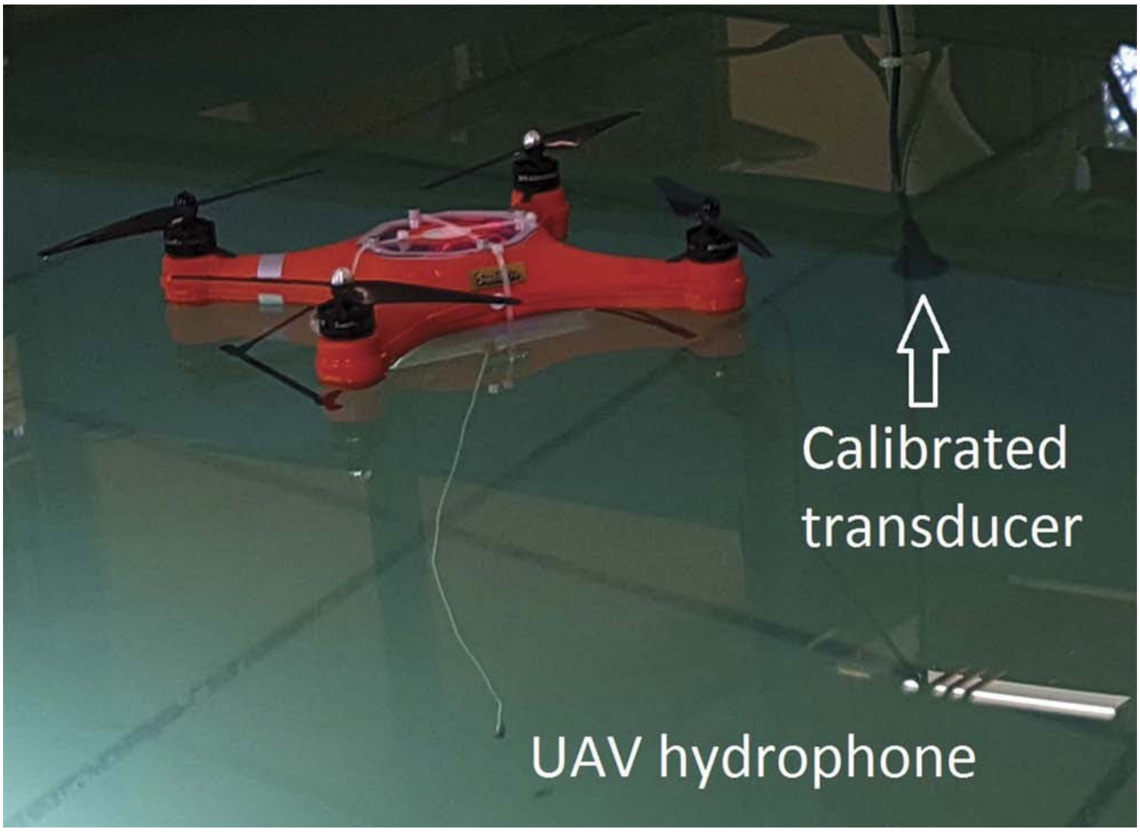

Figure 2. Showing the UAV on the test tank waters surface.

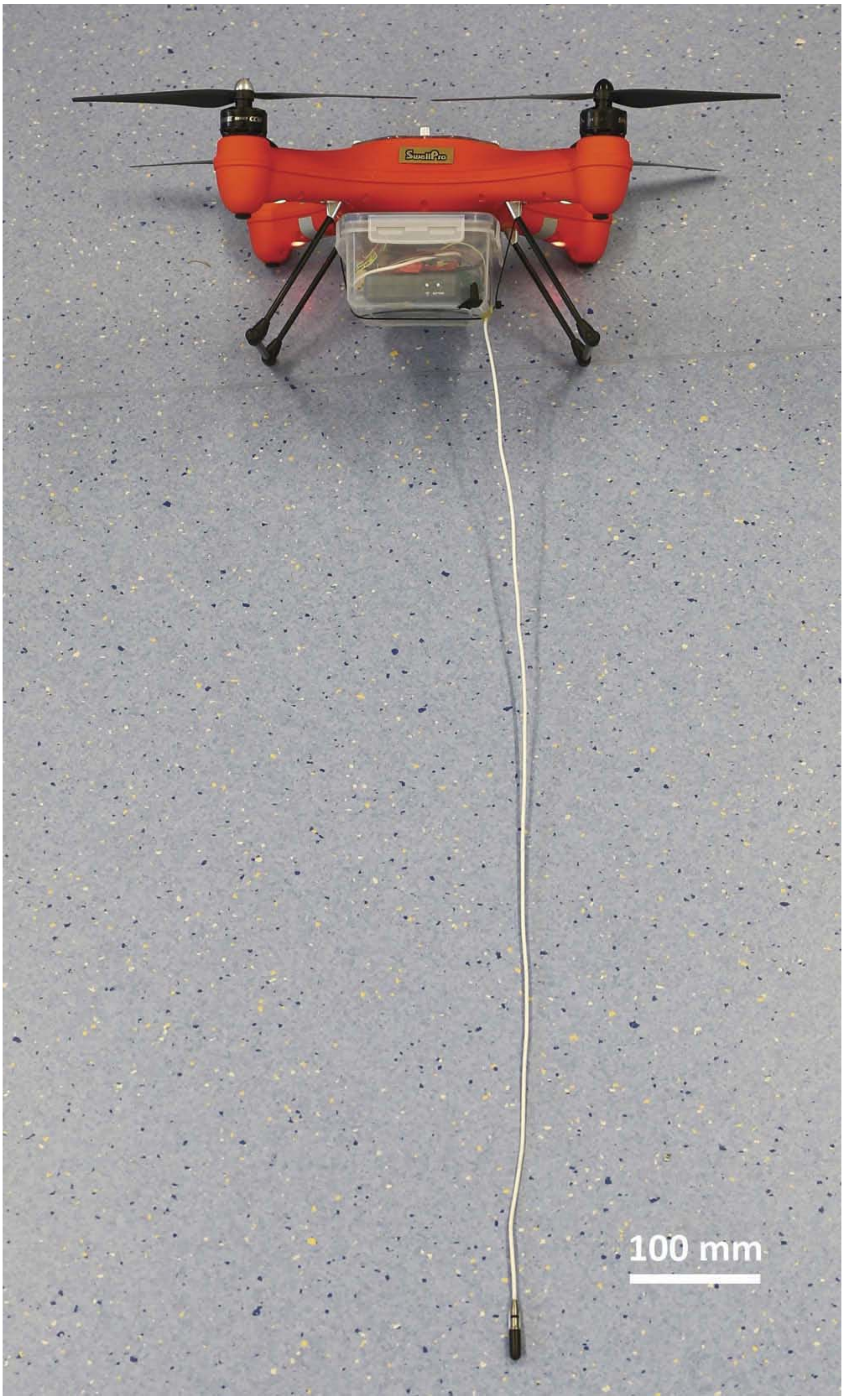

Figure 3. Scaled image of the Splashdrone system.

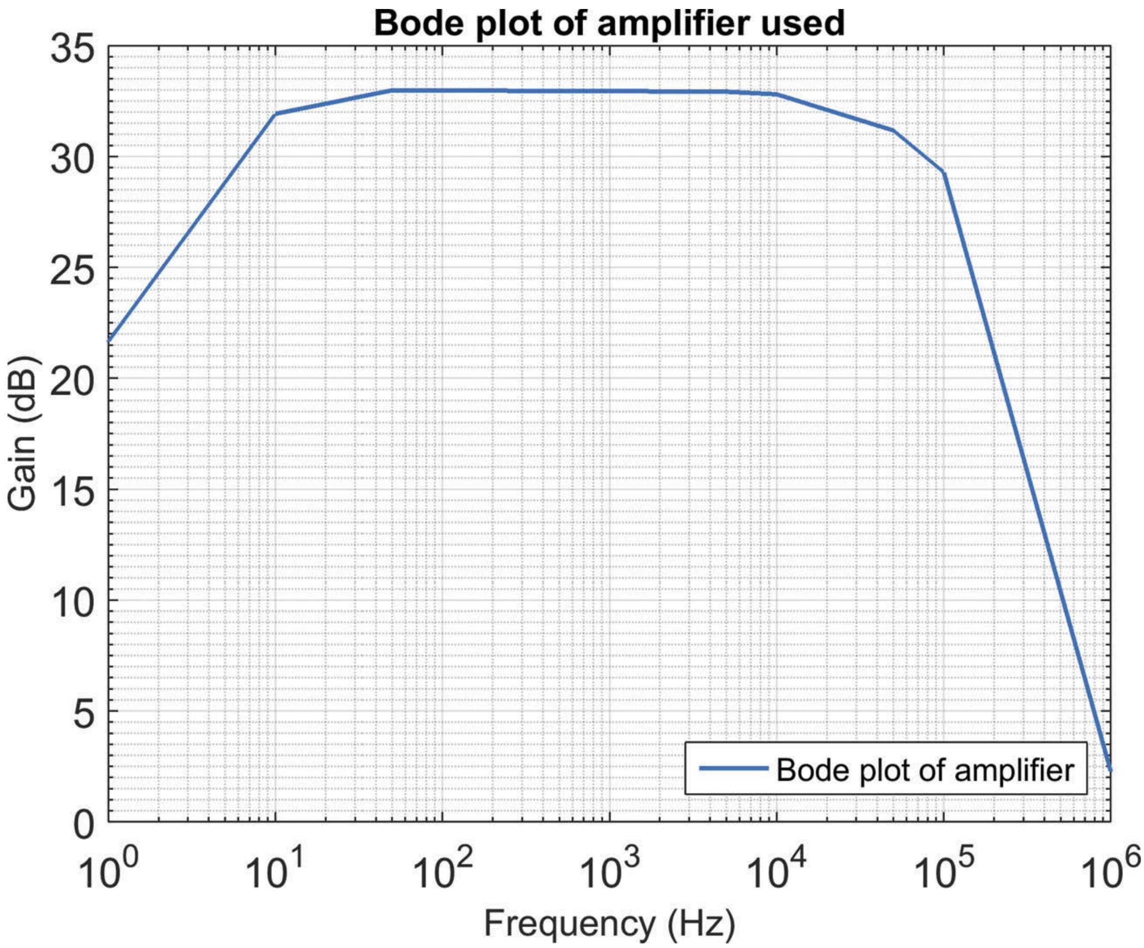

Figure 4. Bode plot showing frequency response of amplifier used.

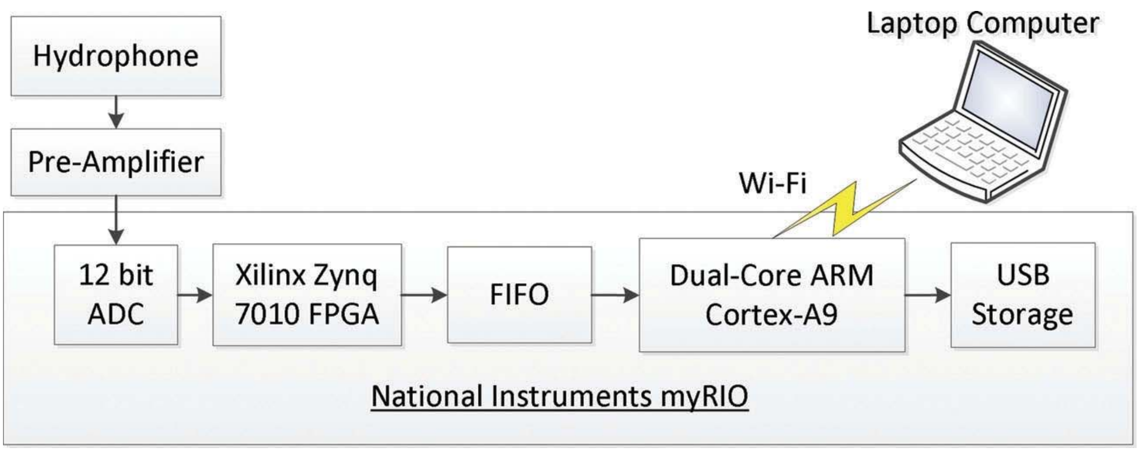

Figure 5. Diagram of the DAQ system.

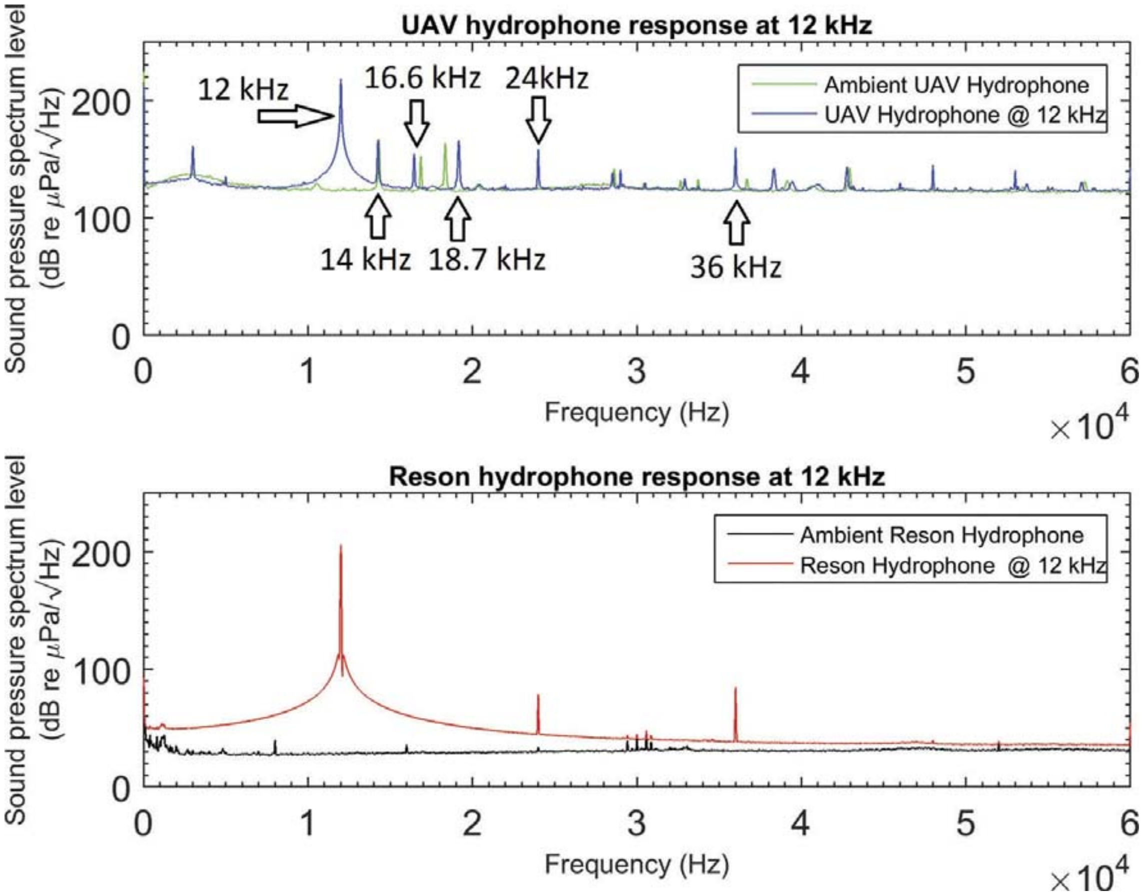

Figure 6. PSD of both hydrophones at a frequency of 12 kHz.

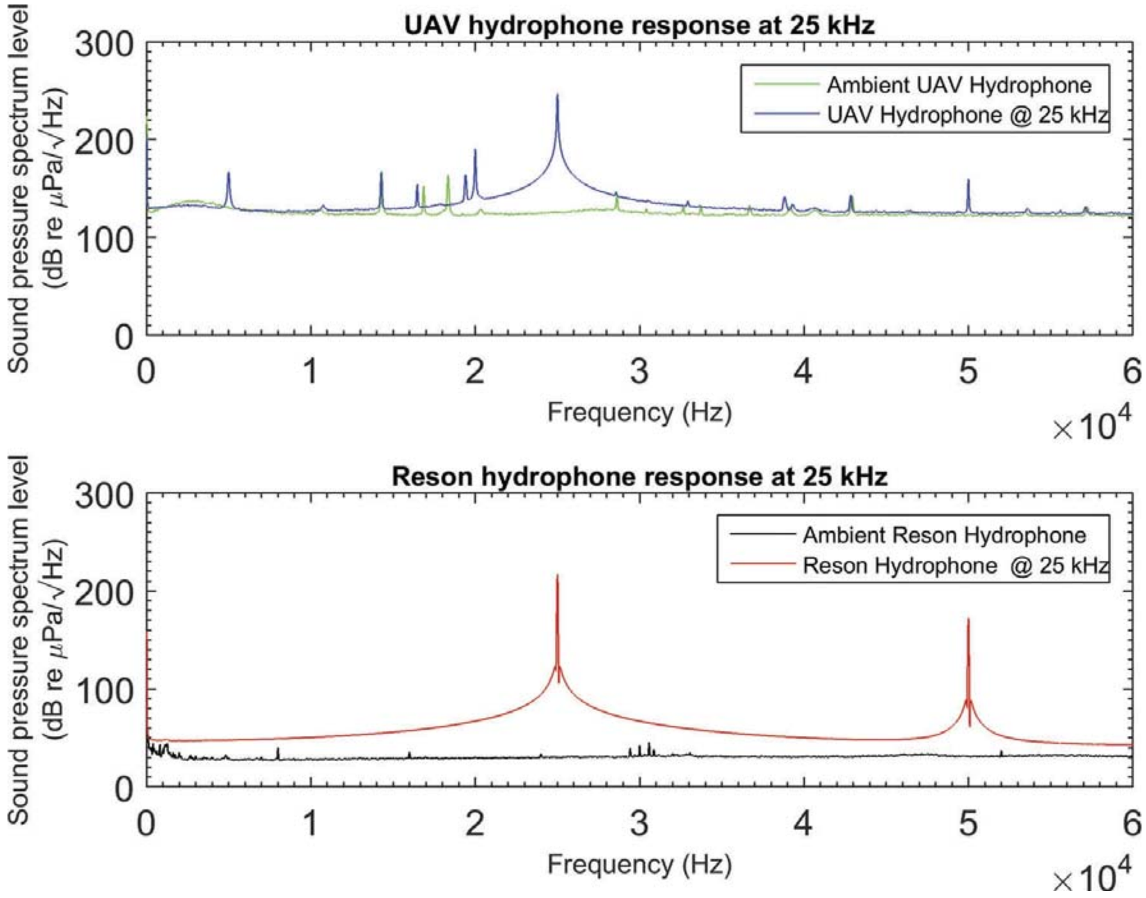

Figure 7. PSD of both hydrophones at a frequency of 25 kHz.

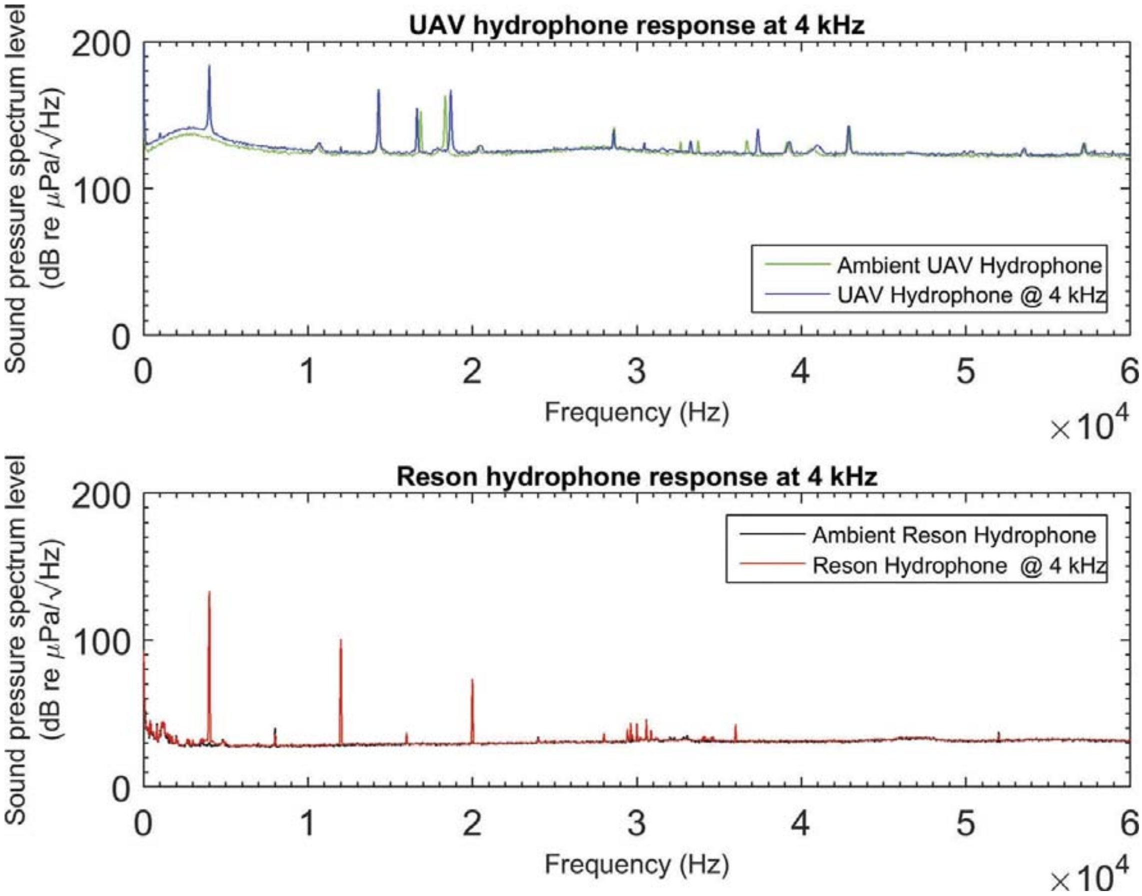

Figure 8. PSD of both hydrophones at a frequency of 4 kHz.