A Portable, Self-contained, 5MSa/s Data Acquisition System for Broadband, High Frequency Acoustic Beamforming

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***Abstract* - Understanding the spatial and temporal structure of ambient noise is a critical factor for estimating the performance of active and passive sonar systems. This is especially true in warm shallow waters where snapping shrimp dominate the ambient noise spectrum over 6 octaves. Snapping shrimp sources can be problematic for active sonar, but are key sources for Ambient Noise Imaging systems. The impulsive nature of snapping shrimp sounds permits the use of a sparse array to beamform on the source, providing each of several channels is sampled at a sufficiently high rate, perhaps 200 kSa/s or higher. If four channels are used to sample hydrophones placed at the vertices of a tetrahedral array in shallow water, the resulting 3-D aperture can be used to estimate the source direction in azimuth and elevation. In general, the altitude of the array will be known, and if the sources are snapping shrimp, they must lie on or very near the seabed. Thus the range may also be deduced and the spatial/temporal source distribution mapped.**

A second motivation for designing a compact high-frequency data acquisition system was to study dolphin echolocation. To learn more about how dolphins might exploit spatial information in the backscattered signal from targets, we need to sample the acoustic field near a target with an array while it is being insonified by echolocation pulses. This requires at least three channels, each sampled at a minimum of 400 kSa/s.

These specifications are certainly achievable with a desktop PC and COTS cards, but this is unsuitable for field deployment and is difficult to make self-contained and power-efficient.

The system we have designed and built is based on COTS components. Its greatest novelty is in using the compact and power-efficient PC104+ platform to drive a high-performance COTS DAQ card using a PCI adapter and in developing a stripped-down embedded Windows NT OS. It permits four analog input channels to be sampled simultaneously at up to 5MSa/s total sampling rate. It is powered by rechargeable Lithium Ion batteries, and records via an Ultra-Wide SCSI bus to a conventional hard drive. It is self-contained and occupies a small cylindrical space that allows it to be packaged in a low-cost pressure casing, weighting 16 kg. The aggregated maximum data-recording rate is 60Mb/s but total electronics component cost is lower than commercial solutions with comparable capability. We have configured the system to sample four miniature hydrophones, attached via 8 mm OD, fluid-filled flexible tubes to permit arbitrary array shapes to be made. It is suitable for use from a small vessel and has a maximum operating depth of 100m.

The system has been used in a recent experiment in collaboration with the University of Hawaii to study the characteristic backscatter signals from dolphin echolocation of targets. The waterproof, compact and unobtrusive package permits its use in confined spaces without disturbing the dolphin behavior or dealing with protecting sensitive electronic equipment from splashes. In the future, we plan to use the system to study high-frequency source distributions in warm shallow water.

This paper describes the system and presents some sample data from the dolphin echolocation study.

I. INTRODUCTION

This acquisition system development was initiated as a hardware upgrade to one of the Acoustic Research Laboratory's research projects to study ambient noise distribution in warm shallow waters [1] and as a research tool to study backscattered signals from targets insonified by dolphin echolocation pulses in cross-modal experiments [3]. Nevertheless, the ARL realised the usefulness of designing a more generalised high-speed data acquisition system that can be easily reconfigured to suit various research needs that require synchronised multi-channel data acquisition so that the data can be beamformed if required.

Therefore, the electronic system was designed to easily accept industrial devices so that one can swap and mix the different modules in order to meet experimental needs. These modules are generally categorised into: high impedance analog front-end, embedded CPU, storage subsystem, data acquisition module, power supply module, transducer and transducer array frame. These modules are highly orthogonal to each other so that one can swap different parts within the same module category freely.

Since the nominal size of the electronics package is small, the system can be easily adapted to various operating situations, i.e. as a submerged acquisition system attached to a small surface vessel, ROV or AUV or beside a pool, etc.

The following sections will describe the building blocks of the acquisition system and their possible alternate modules/configuration in respective modules. The performance of the hardware setup used for the echolocation studies will be briefly described. The discussion will continue with two application examples followed by sample data collected from the dolphin echolocation study. In short, the system is a highly modular, general-purpose high-speed data recording system that is compact and low cost.

II. SYSTEM DESCRIPTION

A. Electronics Design and Integration

In order to optimise the flexibility of the system configuration, it was designed to conform to a popular industrial form factor, interconnection interfaces, and signal protocols. This allows it to accept widely available commercial/industrial COTS products, thus increasing the integration options and lowering the cost. The following descriptions will be mainly based on the setup used in the dolphin echolocation study, a collaboration study with The Dolphin Institute in Hawaii, which was one of the various possible configurations.

The system consists of a processor unit around which the rest of the digital modules operate. It is the main coordinator between various processes such as data acquisition, storage, book keeping and user interaction. A PC based embedded system is selected as it supports a wide range of commercial PC peripheral interfaces, which not only provide us an easy way to integrate with high end commercial peripherals, but also a wide range of development tools. A sophisticated PCI data acquisition card is used to convert analog signals from a custom-made signal conditioning circuitry into digital data. The acquired data is then stored into a high-speed hard disk through a PCI-to-SCSI160 adapter, optimizing the performances of continuous high-speed data logging.

Although these components can be substituted to upgraded/relaxed system performance, one would need to carefully balance the requirement of performance and power consumption when integrating a stand-alone system that is battery operated.

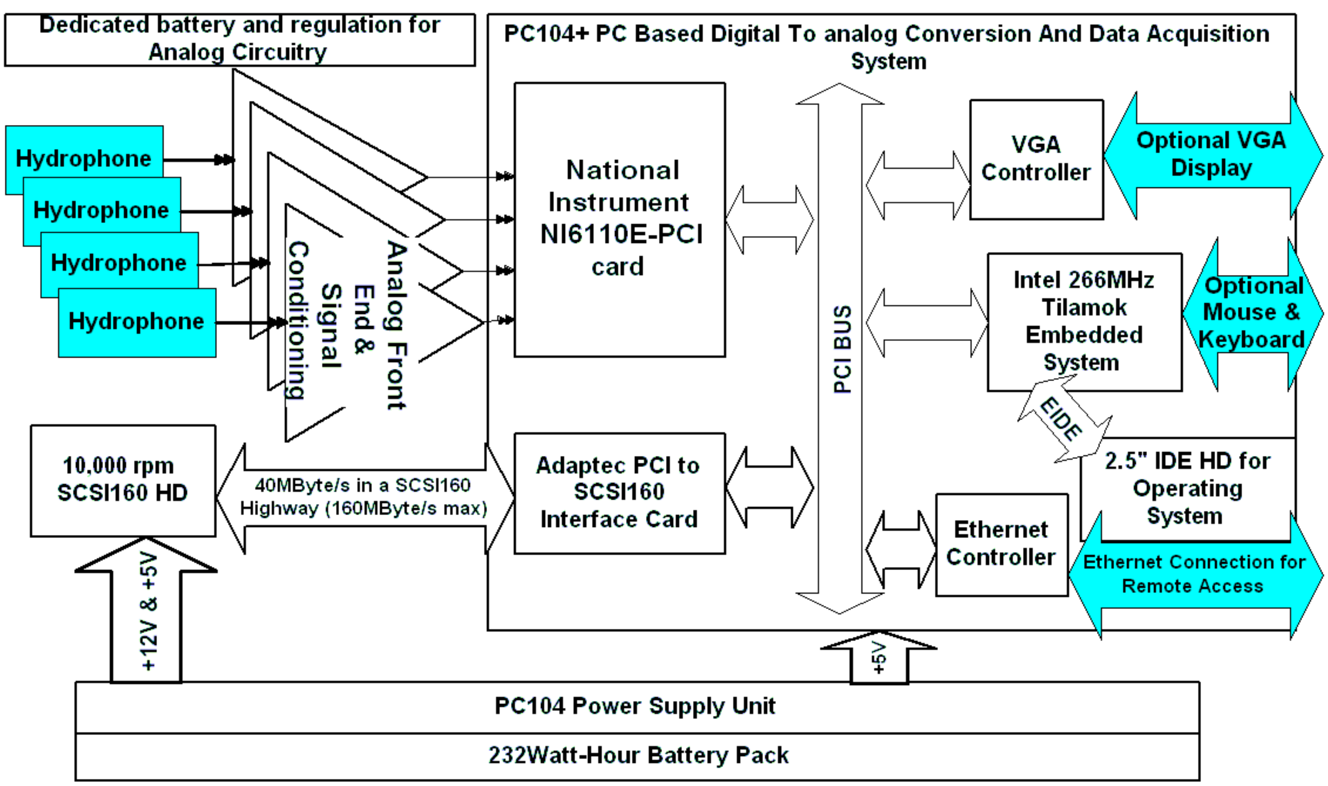

Fig. 1 Simplified block diagram of the data acquisition system

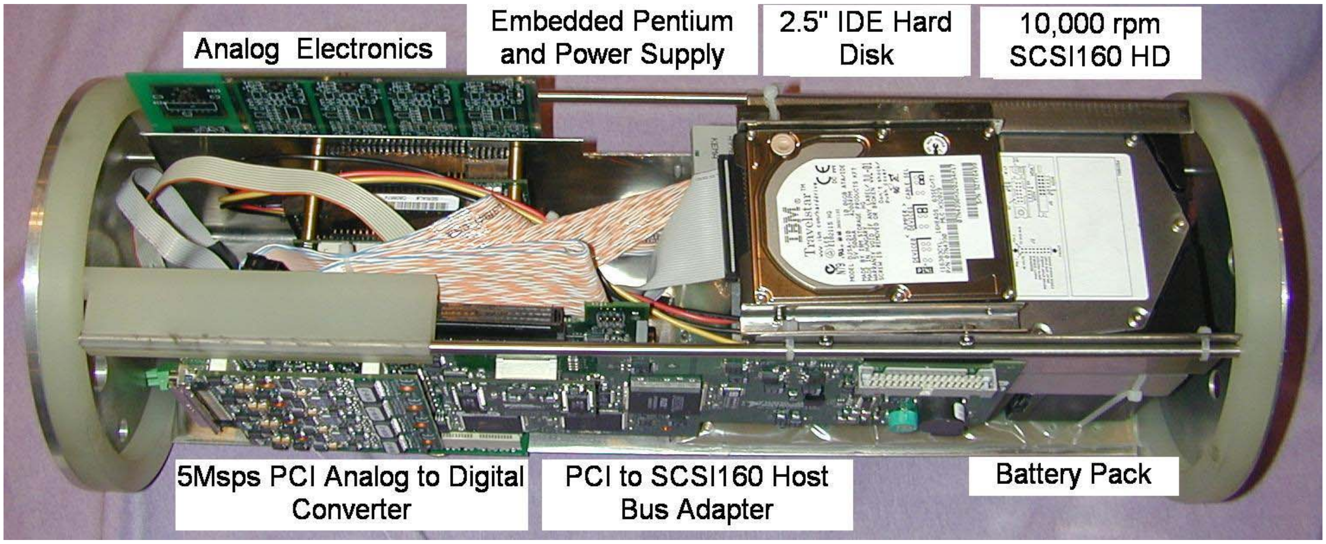

Fig. 2 Assembled electronics Package

Fig. 1 shows a simplified block diagram of the completed data acquisition system whereas Fig. 2 shows the fully assembled acquisition electronics. Blocks colored in blue within Fig. 1 indicate interconnection connectors or components located outside the watertight housing. Each component will be described in detail in the following sections.

B. Main Processor User Control and Storage

1) Embedded CPU and the Operating Systems Used

An embedded industrial PC based on Intel's low power 266MHz Pentium MMX in PC104+ form factor is used as the main CPU. It provides all the peripheral interfaces that exist in a normal PC such as PCI bus, ISA bus, parallel port, serial port, USB hub, Enhanced IDE interface, mouse interface and keyboard interface. The System includes a built in VGA processor to facilitate direct connection to a standard SVGA display during development. On top of these, the system also equipped with a built in Ethernet controller enabling remote administration of the acquisition system. A 128MB SODIM DRAM is installed to provide enough buffers to facilitate a continuous data streaming process. For users who need higher processor power, a number of PC104+ high-speed processor modules up to Pentium III are available in the market. However, the power consumption and heat dissipation requirement will increase significantly.

Embedded Windows NT 4.0 is selected is the operating system (OS) to support the operations of the whole acquisition system. This operating system provides a means to selectively include and compile a custom Windows NT with only the necessary modules needed by the application and thus is optimum in size. The benefit of reduced OS size is not the main advantage, but rather the improved performance due to the reduced internal activities within the OS kernel. Apart from this, the OS comes with a built-in graphical remote administration facility, which allows the acquisition system to be controlled from any remote location through a network connection. Since Embedded Windows NT is using the same software/drivers that a normal Windows NT uses for its peripheral devices, we can take advantage of the various off the shelf high performance peripherals without having to worry about writing a low level code to control it.

As an alternate OS to Windows NT, Linux could be used; system performance would likely be increased as it normally has less operation overhead and come with in depth fine-tuning capabilities. On top of that, there are a number of commercially available real-time kernel and embedded OS available to Intel's x86 platforms that are highly optimised for mission critical processes.

2) Data Acquisition Electronics and High Speed Streaming Storage System

The data acquisition backend is chosen to be National Instrument's NI6110E-PCI, an off the shelf plug and play, jumper less but fully software configurable, multifunction analog to digital converter module (ADC) in full-size standard PCI edge card. Since PC104+ uses a 4 by 30 stacked pin header for industrial PCI signals rather than the normal edge card form factor, a conversion card is used to interface it to the normal edge cards. This makes the system compliant to most commercial PCI cards. This ADC card provides up to four independent input channels of 12-bit resolution with aggregated simultaneous sampling rate of up to 5MSa/s and configurable input voltage range from ±200mV to ±42V.

During the dolphin echolocation study, the sampling rate on each of 4 channels was programmed to 500kSa/s based on the tradeoffs among various limiting parameters such as power consumption, storage capacity, amount of system buffer available to the data acquisition module, and the streaming rate of data into storage. In order to obtain an optimised voltage resolution, the ADC input range was set to $\pm$2V, giving quantization noise of about 1mV. More details of the analog circuits will be discussed in a later section.

Although the PCI data acquisition card claimed to provide up to 5MSa/s continuous sampling and data streaming into hard disk, the actual through put is limited by the overall performance of the integrated system, which in turn depends on the performance of each subsystem. Since a lower range CPU was chosen (to conserve power), the storage system was selected to be a high-end system in order not to load up the processor any more than necessary. A SCSI160 solution was chosen because of its superior performance among the other solutions that are tested such as 1Gb/s Fiber channel Storage Area Network, UW SCISI-2, and Fast IDE. The SCSI160 solution consisted of Adaptec's new commercial Ultra-160 PCI Host Adapter and Seagate's 10,000rpm commercial SCSI160 hard disk. The data acquisition software ran in Lab-View, a popular graphical programming language by National Instrument. Fig. 3 shows the picture of the ADC card (bottom) and SCSI160 storage host bus adapter (top).

Fig. 3 A 5-MSa/s data acquisition card and 160MB/s SCSI bus for storage

3) User Control and Remote Administration of the Data Acquisition

The data acquisition system can be controlled in various ways. During the development phase, a set of normal peripherals such as a keyboard, mouse and monitor can be connected. This solution has also been tested with a multi-core cable of 10 meters length.

Another way of communicating with the system is to network the acquisition system with a desktop or laptop PC running Microsoft Netmeeting. The built in remote administration facility allows Netmeeting to emulate the acquisition system's desktop user interface by transferring the display and user control data packet (mouse and keyboard) between the two nodes via TCP/IP. This can be done either using an Ethernet cable or by sharing an optical link used by the Fibre Channel storage solution, if Fibre Channel is used.

Apart from that, for a total stand-alone implementation, a self-activated data acquisition program can be installed to perform pre-set acquisition sequences. Other means of wireless communications such as an acoustic modem can also be integrated to control it.

C. Power Supply Module

The electric power to the system can be supplied in two ways; one is using an internal battery pack while the other is to run an external DC-supply wire. The first is suitable for stand-alone operation whereas the later is more suitable when operating near land.

In the case of the internal battery pack solution, six units of Sony's standard 7.2VLi-Ion battery packs are combined to provide enough chemical energy to power the entire system. Since these batteries are standard off-the-shelf items, their cost is relatively low. A DC-to-DC converter in industrial PC104 form factor is used to generate regulated supplies of +5V and +12V required by the various modules at the efficiency of 80% to 92%. The system nominally runs at 45W at full activity, at which level our current battery pack allows us to fill up an entire 80GByte SCSI hard disk. When the acquisition process is sparse, a power management scheme can be employed to extend the battery life. As for the DC-supply wiring solution, an industrial AC/DC is used to tap a nearby AC supply and provide a regulated DC voltage of 7 to 30V for the internal DC/DC module.

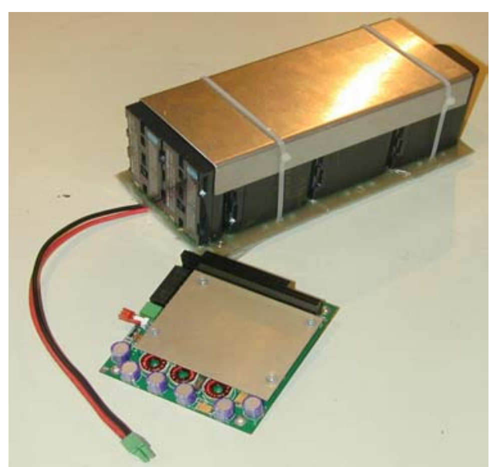

Fig. 4 PC104 Form Factor DC-to-DC Converter and Battery Pack.

D. *Analog Front-end for High Impedance Hydrophones*

The hydrophones used are commercially available miniature hydrophones, which offer a wide useable frequency range of up to 170kHz with omni directional receiving sensitivity in both X and Y planes. The hydrophone is supplied with a thin (2mm diameter) but high quality mini coax cable in order to avoid any scattering of signals of interest. Because of its small diameter, the cable is rather fragile. An Oil-filed silicone tube is used to contain the cable in order to provide protection with minimised acoustic impedance disturbance, see Fig. 5.

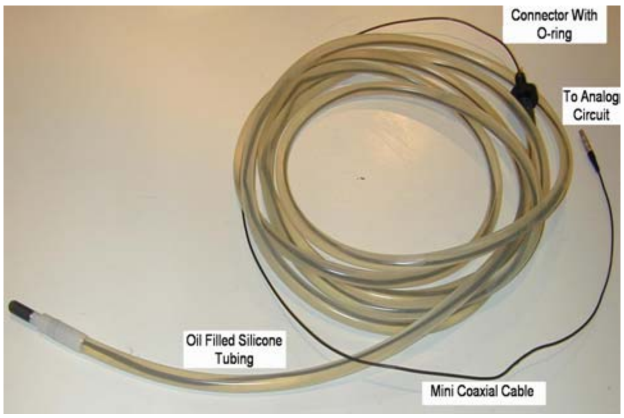

Fig. 5 High performance hydrophone in protective cover

In principle, any other hydrophone can be used with some modification to the analog front end to carefully match the impedance.

1) High Impedance Analog Front End

Although most PCI data acquisition cards have built in analog front ends, not all of them are suitable for interfacing with high impedance sources. A high impedance source buffer should be introduced between the hydrophone and the acquisition card to avoid loading the sensor. Obtaining a clean signal from a high impedance source is not easy when the bandwidth is large and the input signal level is extremely small. This is because any noise parameters exhibited by a device within the chain (such as op amps, filters etc.) will be integrated across the whole bandwidth of interest and since the signal level is small, these noises become significant. The selection of the first stage op amp becomes an important task as it contributes most to the noise. The buffered signal is then passed through a chain of medium range amplifiers to provide selectable gains and signal conditioning before being feed into the ADC's analog circuitry.

A Piezoelectric Hydrophone is a charge emitting transducer. In order to transfer input charge to output voltage change, extreme care must be given to the first stage. There are two main realizations: One is the well-known charge amplifier and the other is the high impedance voltage follower. Each has it's own advantages and disadvantages. The high input impedance follower has a more easily controlled noise gain, thus achieving better noise performance in practice. The disadvantage is its high sensitivity to any capacitance (i.e. capacitance of cables) between the piezoelectric and its input. Therefore, the implementation is limited to applications where the piezoelectric transducer is located relatively close to the analog first stage. The charge amplifier, on the other hand, is suitable for applications where piezoelectric sensor is connected via a long cable with the cost of slightly increased noise. We selected the high impedance follower since our cabling distance is relatively short.

Since the current noise of internal bias circuitry may get coupled into the input signal via the FET op amp's gate-to-source capacitance and appears as extra input voltage noise, providing a similar bias current at the other op amp input will tend to cancel it. This is done by providing the op amp's inverting input with an equivalent capacitance that matches the sensor's capacitance. A large matching resistance is also provided to reduce the DC noise. A DC servo configuration is added to maintain the output swing around the signal ground. In order to further reduce the noise induced by bias current, the rail power supply to the analog circuits is reduced to $\pm$5V, which reduces power dissipation and gate-to-junction leakage current. This precaution is extended to the entire analog circuitry supply. Before being fed to the op amp, the power supply is carefully filtered by providing LC networks in order to minimise both high and low frequency noises in the power line.

Based on prototype performance tests along with other considerations such as packaging size, implementation limitations etc. A JFET op amp is currently selected to form the analog first stage. It is chosen because of its excellent voltage noise performance comparable to a bipolar and yet maintaining the low current noise of a FET device (which are respectively 6nV/$\sqrt{}$Hz and 1fA/$\sqrt{}$Hz). It presents an extremely high input resistance of $10^{13}\Omega$, a very low input capacitance of 1.5pF and a large Gain Bandwidth Product of 5.3MHz. Unfortunately, its output offset is relatively high (2mV) at the first stage but this is rectified by employing a DC servo circuitry. Another main reason for the selection is its availability in a small physical package.

2) Pre-selectable Gain Stage

The signal is buffered from the high impedance source and presented to the rest of the circuitry as a low impedance signal. A low voltage noise op-amp with large gain-bandwidth product suffices for the following stages. An ultra low harmonic distortion (-120dB at 20kHz) and ultra low voltage noise (0.9nV/√Hz typical) op amp, is selected for the gain stage. Although the current noise is relatively high (2pA/√Hz), this isn't much of a concern now because we are now interfacing to a very low impedance source (the output impedance of the FET first stage). In such a situation the voltage noise contribution is dominant and contributions from other source can be neglected [7]. The op-amp provides a large gain bandwidth product that enables us to implement a single IC gain stage and therefore minimise noise. The op-amp is also designed to operate stably with extremely low external resistor networks and this helps improve the total noise performance by bringing thermal noise (Johnson noise) to a negligible level.

3) High-Pass and Anti-Aliasing Filter

The amplified signal is first passed through a simple 2-pole active high pass filter to attenuate unwanted signals below 800Hz. This helps to avoid lower frequency signals (that are normally large in amplitude) saturating the dynamic range.

We band limit our signals to the Nyquist criteria before feeding them into the ADC by providing a sharp anti-aliasing filter. In order to minimise signal distortion, the low pass is preferred to have a linear phase response. Unfortunately linear phase filters normally have shallow attenuation curves and hence insufficient attenuation rate. To overcome this, a sharp 8^{th} order low pass filter is implemented but the cutoff frequency is purposefully placed at a higher frequency compared to the band of interest so that the non-linear phase response region falls outside our band of interest. The filter therefore provides relatively linear phase response of less than 5usec group delay from DC until 170kHz, which covers the entire usable frequency offered by the hydrophone used (our frequency range of interest). With an 8^{th} order filter, some 64dB attenuation is imposed from 200kHz to 250kHz, where each of our ADC channel is acquiring at 500kSa/s. Thus signal aliasing is negligible and optimum signals with linear phase (up to 170kHz) are ensured.

4) PCB Design

Because of the very low input level and high source impedance, the PCB design included a number of precautions. Those traces that connected directly to the sensor were provided with guard rings to block any in circuit electromagnetic disturbance. Solder masking was removed in the sensitive region (i.e. all areas within the guard ring) to avoid impedance changes of the traces. Another important precaution taken was the separation of the large signal current return path (i.e. signal return from the outputs of the op amps) and the small signal current return path (i.e. signal return of the op amp input pins). Sufficient local power and ground coupling was provided to every op amp and careful considerations have been given to decide where it should be coupled. Fig. 6 shows the PCB assembly.

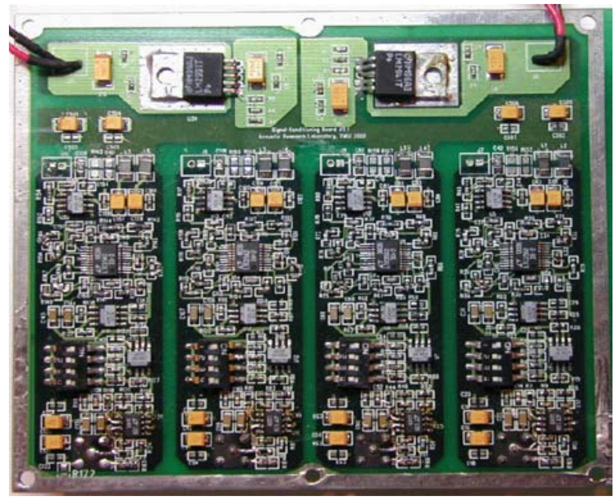

Fig. 6 Signal Conditioning Printed Circuit Board

III. MECHANICAL HOUSING

A modified off-the-shelf watertight housing from Prevco, adapted to our requirement, is used to pack the electronics. The housing was a low cost molded plastic pressure case rated up to 100m-water depth. The design exhibits a threaded collar securing mechanism and no screwing or bolting was needed at the end cap to hold the end caps in position; see Fig. 7. The end caps were provided with O-ring seals to make the internal volume waterproof. The small electronics package size allows us to use a low cost housing with relatively inexpensive material and yet rigid enough for shallow water applications. If deeper water deployment were intended, the cost for mechanical housing would still be relatively low because of its size and simplicity. Watertight connectors were mounted on the end caps through which the sensors and the electronics can be accessed.

A custom made cylindrical cage was used to mount the electronic modules into a single electronics package that slots into the housing. The cage was built as a holding structure rather than a strong mounting structure in order to reduce the cage thickness and diameter of the supporting pillars to conserve as much space as possible to house equipment. In order to gain structural strength, it was built as a tight fit cylindrical to the underwater housing to utilise the internal wall of the housing as main mechanical support. Important analog electronics were provided with shields to avoid any electromagnetic disturbance (EMI) caused by internal processor clocking and the motor noise of hard disks.

Fig. 7 Underwater housing with electronics packed inside.

IV. PROTOTYPE PERFORMANCE

The total rms noise level of the entire customised front-end analog and signal-conditioning circuit was measured to be 1.3-1.5 mV (corresponding to a maximum of 12mV peak-to-peak noise or less 95% of the time since the noise is approximately Gaussian) at 49 dB gain. This consumes less than 4 bits to toggle at the peak-to-peak noise, but toggles less than 2 bits at the rms value. The measured rms noise value was twice the ideal/theoretical noise performance yet considered acceptable as it takes only 1 LSB of our 12-bit data acquisition system working at ±2V and theoretical minima are never achieved in practical circuits.

The dolphin echolocation experiment does not need to continuously acquire data for a long time. Therefore, the system was optimised more towards power consumption and the performance of continuous data collection was relaxed. The system was able to simultaneously acquire some 35 million continuous samples on each of four channels. Another bench top testing has been conducted with increased processor speed (550MHz) where a 20GB hard drive could be filled up with continuous data at this sampling rate.

V. APPLICATION EXAMPLES

The following sections will describe two application examples that are currently in progress at ARL.

A. Source Distribution Study in Warm Shallow Water

This project requires us to build a system to investigate the spatial and temporal characteristics of underwater acoustic transients. In general, the system should be able to accurately estimate the directivity and ambient noise signal density; or in particular, the range and direction of sources on the seabed. The first objective should be interesting in measuring the less published ambient noise horizontal directivity and the later is useful to gain an understanding of source distribution (particularly but not limited to biological sources). One of the major biological contributors to the shallow water high frequency ambient noise are snapping shrimp, with a spectrum that extends from about 2 kHz to over 300 kHz [2]. In view of this, the acquisition system is configured to cover the major part of the above spectrum. As we plan to study the directionality of the ambient noise the system should be capable of sampling 3D space.

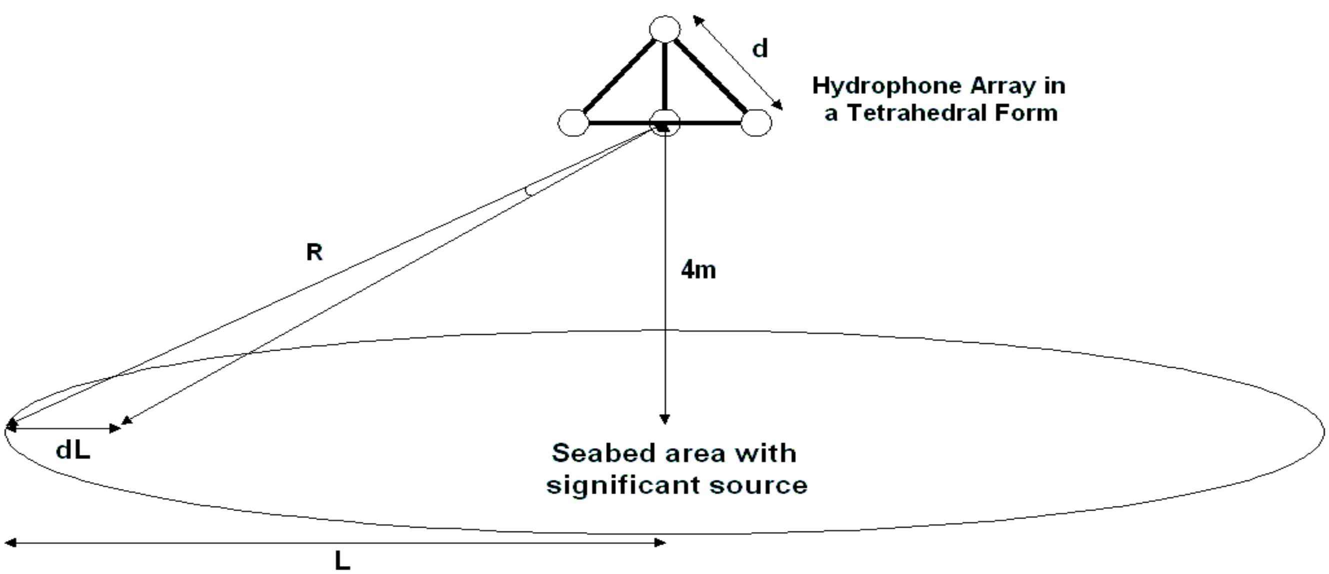

Fig. 8 Structural setup of the ambient noise source distribution study

1) Sensor Mounting – Tetrahedral Frame

The successful determination of the 3D directivity of ambient noise relies on four omni-directional hydrophones that are positioned at the apexes of a tetrahedron forming a 3D sparse array. With three hydrophones positioned at the vertices of an equilateral triangle, we can beamform incoming waves in a plane, leaving an ambiguity in the third dimension. A fourth hydrophone is introduced above the centroid of the equilateral triangle to form a tetrahedron. A tetrahedral frame is constructed to hold the sensors and is positioned about 4 meters above the seabed by an adjustable tripod. Fig. 8 shows a picture of the mechanical pre-assembly test

Since the ambient noise consists of broadband acoustic clicks/snaps, hydrophone separations are not restricted to less than half wavelength of the highest frequency of interest as for CW signals that produce grating lobes when the sensor separation exceeds the half wavelength criteria. Thus, the array aperture is desired to large so as to increase the angular resolution, which is a function of the ratio of signal wavelength to aperture size.

Nevertheless, the hydrophone separation should be small enough to distinguish different snaps. Therefore, the propagation delay between farthest hydrophones (which, in the worst case, is about 0.8165 the length of the arm of tetrahedral, *d;* when the wave front is perpendicular to any of the triangle planes) should be kept less than the typical inter-snap interval. Thus the hydrophone separation is determined by the frequency of occurrence of the detectable transient acoustic signals (or snaps) of interest, which is estimated by the following calculation.

The area under investigation is determined by *R* (See Fig. 8), the farthest detectable source distance, from which source energy is attenuated (by spreading loss) to a level that is insufficient for signal processing. Assuming the system gain is set in such that the nearest possible biological sources (4m directly below the tripod) are amplified to almost the full input voltage range of the ADC (i.e. +-2V considering the same system configuration described in previous sections); the ADC's resolution is 12bit (72dB); and the analog peak-to-peak noise is 12mV, about 50dB of system dynamic range is useable. If the system would need 12dB of signal processing SNR to beamform the signals, a similar source that is attenuated by 38dB because of propagation loss will not be beamformable. Assuming spherical spreading, the spreading loss is 20log10(R); therefore R can be estimated to be about 80 meters. Hence the value of *L* (Fig. 8) is approximated to 79 meters, translating to an area of coverage of about 19606 meter^2.

We estimate a typical snap density to be in the region of 0.1 snaps/second/meter^2, so that the frequency of snap occurrence has a statistical mean value of about 1961 snaps/second within the area under investigation. Assuming the snap probability is a Poisson distribution, and the source distribution is homogeneous, it is estimated that the snaps will occur no more frequently than about 2100 snaps/second 95% of the time. Assuming a nominal sound speed of 1500m/s in seawater, the snaps are therefore physically separated by more than 0.7 meter 95% of the time. This is used as a guideline when determining *d*, which in turns determines the size of the tetrahedral array. The exact spacing between the hydrophones will be fixed after a trial data collection, but setting *d* to 1m appears reasonable. This in turn provides an angular resolution of about 10^{-2} radians at 150 kHz.

2) Supporting Structure – A Stainless Steel Tripod

It is preferable to maximise the height in order to reduce the resolution error caused by *dL* (see Fig. 8). A telescopically adjustable stainless steel tripod from a previous experiment is used to support the

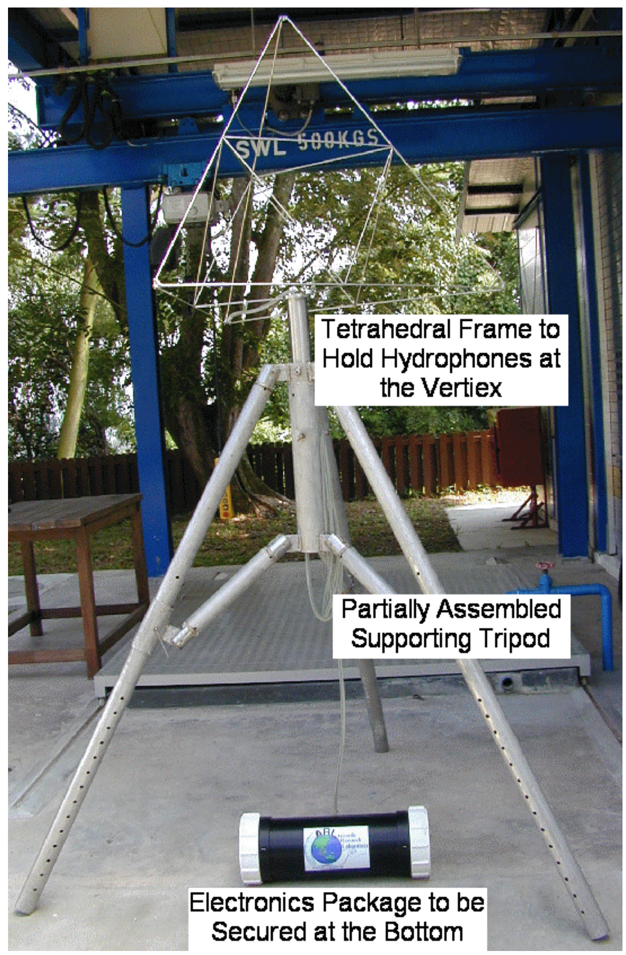

Fig. 9 A partially assembled system for the high frequency ambient noise study.

array more than 4m (its maximum extension) above the seabed. The structure is made modular to ease the process of site installation and transportation. The tripod consists of main body, vertical extension rod, leg extensions, and feet. The degree of leg openings is made adjustable to accommodate different drag forces at different sea conditions (30-degree leg opening for calm waters or 45-degree leg opening when current is stronger) and seabed contour. Nevertheless, the sensor array is designed such that it induces minimum drag at the top of the tripod and a 30-degree opening would be sufficient in almost all cases.

The height of the tripod is adjustable from 2.3m to more than 4m to accommodate variations of the uneven seabed. This is accomplished by adjusting the telescopic coupling of the extensions legs and main body, as well as the telescopic coupling between the vertical extension rod and the main body.

Tripods can be supported on optional feet that are designed to have a large contact surface area with the seabed, to prevent the structure from sinking into a soft seabed composite such as silt, muddy etc.

3) Prototype Array and Estimated Performance

Fig. 9 shows a partially assembled array, where the tripod will have more extension legs and a vertical rod during the actual experiment. At the farthest range of interest, approximately 80 m distant, the error in locating a source will be on the order of 1 m in azimuth and up to 20 m in range. Sources nearer the array will be resolved with much improved accuracy, particularly in range.

B. Study of Characteristic Backscatter Signals from Dolphin Echolocation of Targets

The second application example is the study of characteristic backscatter signals from dolphin echolocation on targets in collaboration with The Dolphin Institute in Hawaii. A series of experiments have been conducted to study the dolphin's ability to match objects across the senses of echolocation and vision. It appears that the dolphins are able to represent echolocated objects by their global appearance rather than their 'local' features [3] [4] [5].

We therefore conducted a basic study on the characteristics of the spatial backscattered signals produced by the dolphin's echolocation during the cross-modal experiments on targets.

1) Experiment Methodology and Setup

In order to be able to exactly reproduce the environment of the cross-modal experiments and analyse the reflected signal without interference, the dolphin was replaced with a broadband high frequency underwater transducer transmitting a series of recorded dolphin echolocation signals from the above-mentioned experiments. The original experimental setup with the original objects and object enclosure was maintained.

Four hydrophone sensors were arranged as a planar sensor array on the acoustic transparent window at the inside of the enclosure where the objects were placed. They were arranged in a triangle with the fourth sensor placed in the middle of the triangle in a plane. The transmitting transducer was placed perpendicular to the plane 400 mm in front of the acoustically transparent window outside the enclosure with a PVC fixture, submersed in the water.

From the previous collection of dolphin echolocation recordings during the dolphin cross-modal experiments, eight "typical" dolphin clicks with different features were selected and assembled into a basic sequence to be repeatedly transmitted. A total of eight different objects were ensonified, and their backscattered signals were recorded simultaneously by the sensor array. The recording was conducted with 500kHz sampling frequency on each channel.

2) Results

Three recordings were conducted on each of the objects, in which each recording contains approximately 320 repeated transmitted sequences. We thus collected 64 different backscattered data recording types (eight click types independently ensonified on eight different objects), each with 960 repeated clicks along with their backscattered signals. Fig. 10 shows a section of waterfall plot of one of the sampled clicks with its backscattered data.

VI. CONCLUSION

A compact, high bandwidth (up to 5MSa/s), simultaneous quad channel general-purpose sampling data acquisition system has been developed. It is highly modular and easily reconfigured to suit different acquisition specifications. It permits 3D spatial beamforming on the data collected. Up to four sensors can be connected to the four synchronised input channels allowing the realizations of different arbitrary array configurations.

The system is designed in such a way that the subsystems are highly orthogonal to each other and compliant to popular interconnection standards in commercial industry. Therefore, users can easily obtain desirable COTS to swap and mix the different modules to meet their own experimental needs. The compact design allows the system to be easily adapted to various operating situations, i.e. as submerged acquisition system either

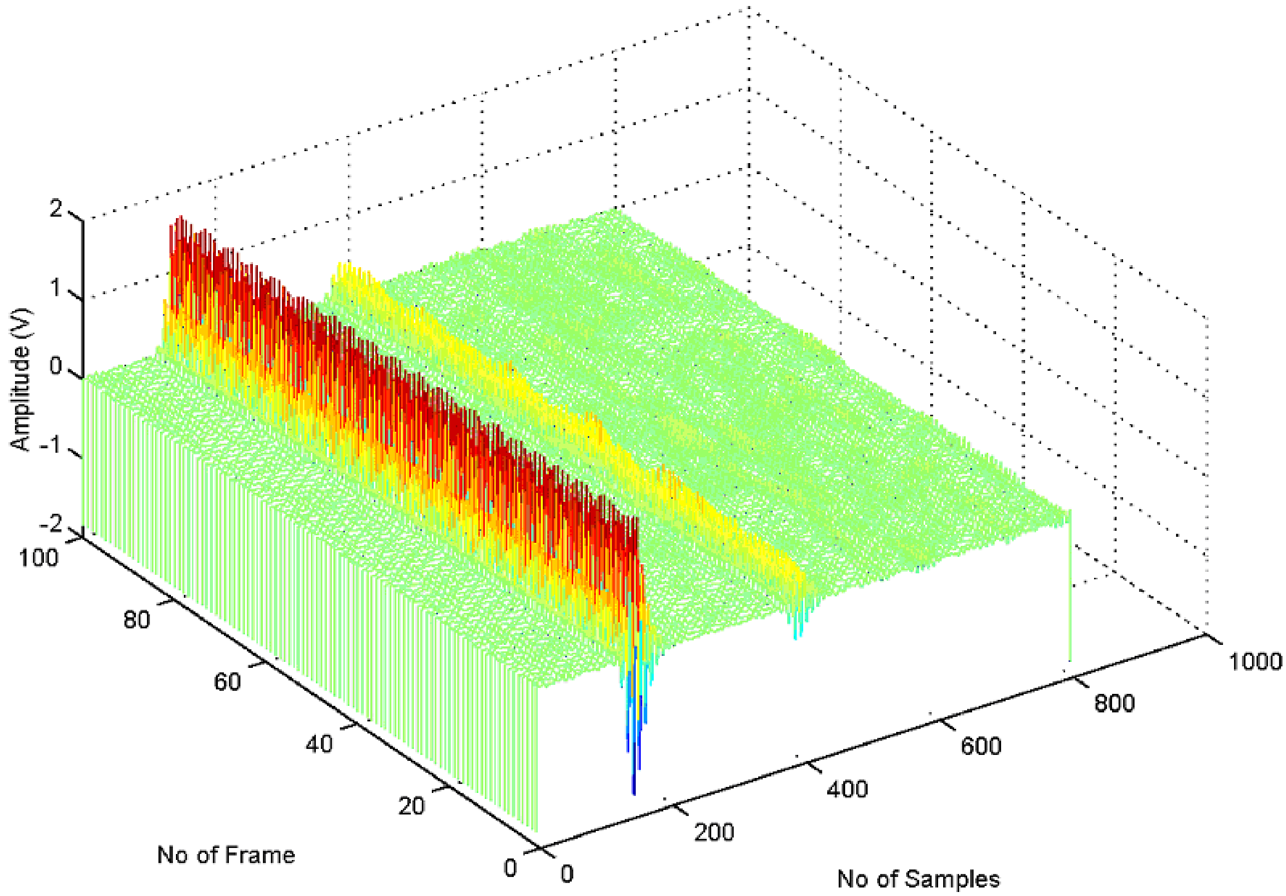

Fig. 10 Waterfall of 100 (out of some 960) repeated "ping" (one of the eight) on a particular target (one of the eight) collected from one of the ADC channels.

anchored/mounted (such as the ambient noise source distribution experiment) on the seabed, operated from a small vessel, or at the edge of a deck or beside a pool (e.g. the dolphin echolocation cross modeling experiment).

Two application examples have been presented and some sample data collected from collaborative work with The Dolphin Institute in Hawaii have been shown.

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