PANDA; A Self-Recovering Shallow Water Acoustic Logger

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***Abstract* - An increasing focus on monitoring the coastal environment and the need to do so without leaving any surface expression to hinder vessel traffic or attract unintended recovery or collateral damage from other marine activities has led to a several developments in building bottom-mounted observation platforms that release to the surface on command or after a fixed delay. Typically these consist of a pressure housing with internal electronics package, a release mechanism, deadweight anchor, buoyancy unit and perhaps a spooled line. If no line is used, the deadweight is released and left on the bottom. This may be unacceptable in terms of environmental impact and undesirable for other reasons, particularly in sensitive areas. A second major disadvantage is that a free-floating released package drifts with current and can easily be lost. If the package is small (desirable if it is to be cheap and easily deployed and recovered) it is then difficult to see on the surface, particularly in rough seas. Expensive VHF transmitters, GPS receivers, strobes, etc., are then required to ensure pick-up. This drives up the cost. The spooled line approach not only recovers the entire system, but also maintains the package tethered to the bottom at a fixed location until pick-up. With GPS standard positioning now accurate to some 5 m rms, this is sufficient to locate even small packages. We present an inexpensive package design that is small, light, deployable by two people and that consists only of a single combined buoyancy, pressure casing and spooled line unit plus an anchor. This is a development of an earlier Pop-up Ambient Noise Data Acquisition (PANDA) system built in 1996. The new unit is based on COTS components, costs under $10k and has been tested at depths from 17-100m acquiring ambient noise and to monitor oceanographic acoustic sources. The design permits various electronics payloads in a modular cage, inserted into a cylindrical pressure housing which has its own release mechanism, around which is wrapped 250m of release line. The PANDA is presently released on a pre-programmed timer. The conceptual design, components and example data from the South China Sea are presented.**

I. INTRODUCTION

Oceanographers, marine biologists and coastal management teams (to name but a few) need to measure ocean properties, often over several days' duration. Conventionally, these measurements are time consuming and require substantial resources. Reducing the size, cost and complication of these resources could allow one to cover a greater area in a lesser time at lower cost. Ideally, one would like to achieve this by designing a simple, inexpensive, autonomous, integrated measurement platform. We believe that this can be achieved if the maximum deployment depth is limited to the continental shelf.

A surface mooring system has several disadvantages. Among these are:

- A surface expression may attract undesirable human attention.
- Surface waves and both surface and water column currents introduce considerable drag and tension on the mooring line from bottom to surface, requiring heavy deadweights and larger mooring lines with considerable buoyancy components to ensure the mooring maintains its position and remains nearly vertical.

These concerns are especially serious in coastal areas, often populated with heavy traffic and unpredictable environmental conditions. It seems inescapable that a bottom-mounted moored system with surface buoy cannot be made as light and simple as we would like.

The alternative is to design a bottom mounted subsurface system. We may thus expect to reduce the size of the mooring line, buoyancy and deadweight. Unfortunately, the usual subsurface system still requires the following components:

- Deadweight to secure system to the bottom
- Acoustic release
- Attachment line to the instrument package
- Instrument package
- Attachment line to the buoyancy component
- Buoyancy component

In addition, the Acoustic Research Laboratory (ARL) requires nothing remain on the seabed after recovery, so as to be ecologically responsible and unobtrusive.

The large number of separate components make the equipment preparation and deployment process a relatively complex task, not well suited to small vessels and limited manpower, perhaps only minimally-trained. A system that integrates as many as possible of the above modules into a single piece would greatly reduce complexity. To avoid the system form becoming too heavy to handle in one piece, the deadweight should remain separate.

Regarding the deadweight, if the decision is made to recover all of the system, leaving nothing behind, then the deadweight can be replaced by a genuine anchor. Anchors are not usually employed due to their increased cost over deadweight, certainly an issue if the weight is to be discarded. The use of an anchor has the substantial advantage that the resistance to dragging of a genuine anchor is much higher (by perhaps a factor of 3-10) than deadweight of similar weight, since an anchor digs into the seabed as it is dragged. The choice of anchor type and weight can also reflect the bottom type and depth/currents expected. A fully-recoverable system can therefore use a much lighter anchor than a comparable system with disposable deadweight.

With these considerations in mind the ARL have improved the design of our earlier version of a Pop-up Ambient Noise Data Acquisition (PANDA) system into one that is highly integrated yet light enough for one man to lift and deploy if necessary (30 kg + anchor). Breaking the total weight into two roughly-equal parts makes it more suitable for small vessel operation without the need of a crane. The end product is an integrated "cable drum" that itself is a floatation buoy as well as a pressure casing with an integrated release mechanism that houses all the sensor electronics and power supply within it. Thus, what one needs to do while using PANDA is to activate the acquisition electronics, attach the anchor onto the free end of the cable, arm the release mechanism and finally release the system into water. Two people are easily sufficient to handle the whole process. Another advantage of the system compared to a conventional acoustic release is that it will be held in position by the anchor after surfacing, rather than drifting after release to the surface, an action that may turn the recovery operation into a drifting search and recovery scenario. The switching off of selective availability last year allows a GPS positioning of the recovery site to within a few tens of metres, even including current uncertainties. In coastal waters, even a small object can be found at such short ranges by a small vessel.

PANDA provides a cylindrical payload bay that can be loaded with a variety of sensor and recording packages, making this a useful and customizable platform. The current ARL system is set up for low bandwidth (1 kHz) but long duration (10 days) continuous acoustic logging. The system is equipped with acoustic data acquisition electronics and a high capacity PC compatible IDE Hard Disk (HD) where the data is stored. It also carries a battery pack of 230 Wh energy capacity. The system has been successfully deployed in up to 100 m water depth in a number of environments. A detailed system description and sample data follow in the following sections.

II. SYSTEM DESIGN AND DESCRIPTION OF CURRENT SYSTEM

A. Overall System Description of PANDA

The PANDA is a platform combining various subsystems, and thus the overall specification depends on the configuration. Nevertheless, we designed the current system with a view towards using it as a basic configuration for common data acquisition.

PANDA can be broadly divided into three main components. One is the integrated housing, which is a pressure casing in which all the dry end electronics are kept, and onto which the wet end sensors are attached. It is modified from an "off the shelf" subsurface flotation buoy with integrated timed release in the shape of a cable drum. An Australian company by the name of Fiomarine makes the basic casing and timed release, normally of only half the length we required. Fiomarine were very supportive in accommodating our requests for modifications, and produced a longer version capable of holding sufficient recovery line for our purposes, spooled onto the casing. When deployed, the PANDA is retained close to the anchor by the 'closed' jaws of the release mechanism at one end of the casing. Since the release jaw is positioned centrally in the end cap, and the internal weight distribution is kept axi-symmetric, the PANDA is stable in a very nearly vertical position, see Fig. 1.

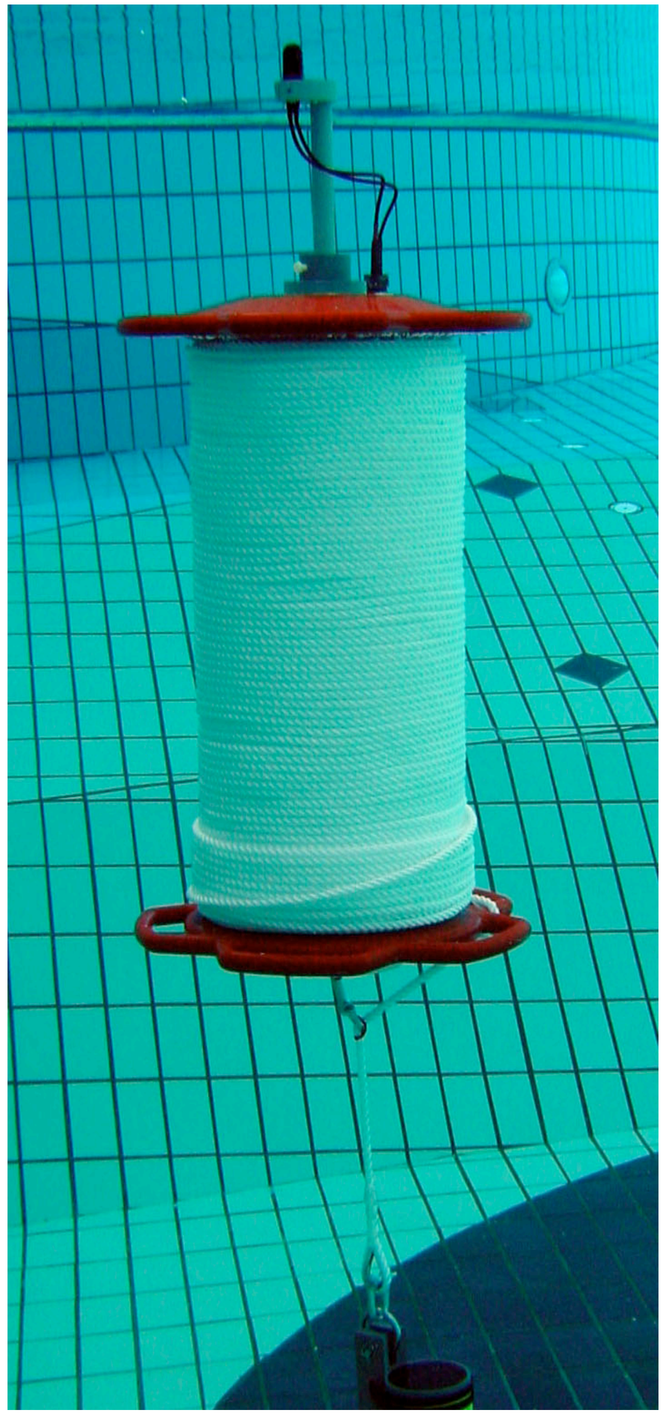

Fig. 1. A complete PANDA deployed for testing in a swimming pool.

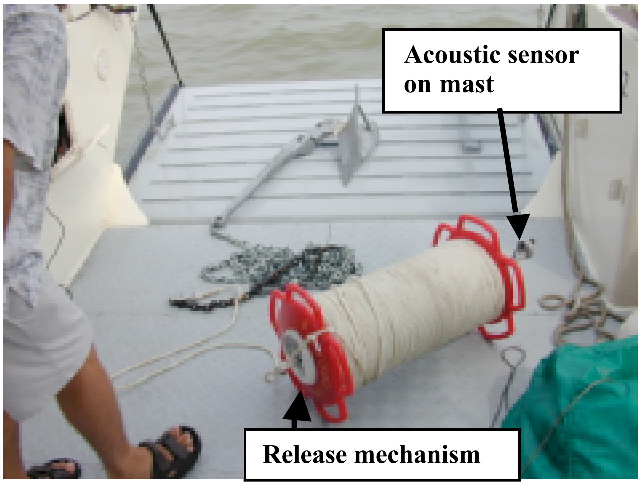

Fig. 2: A PANDA assembled and ready for deployment from a small vessel

Fig.1 shows a PANDA deployed in a swimming pool during testing. The short plastic mast, supporting the hydrophone, can be seen at the top. The recovery line is held by a retaining pin held in the release jaws at the bottom, leading to the anchor. When the release jaw opens, the buoy's buoyancy turns the casing onto its side, and the casing unreels the recovery line under its own buoyancy to the surface. The PANDA remains attached to the anchor on the seabed, preventing surface current induced drifting after release.

The second component is the dry end electronics, including the power supply. These are mounted in a payload cage, which is in turn inserted and secured inside PANDA's internal space. Any electronics with suitable size and weight can be mounted in the cage. Currently, a hydrophone is attached as wet end sensor. A 12 bit, 2 ksps acoustic digitizer supplied by Cornell Laboratory of Ornithology, together with HD storage, occupy the payload cage. We are currently developing a new data acquisition system based on a more advanced microprocessor. Finally, the third component is a 24 kg anchor that holds the entire system in place. Physically, there are only two separate pieces; one is the housing with electronics inside, and the other is the anchor weight. Fig. 2 shows a fully assembled PANDA waiting to be deployed from a small vessel as part of the Asian Seas International Acoustic Experiment (ASIAEX) in the South China Sea.

Table 1 is a simplified specification of the current unit. It contains a single acoustic sensor at 2 ksps, although the system can acquire data up to 25 ksps with some modifications (limited by the processor speed and the operation of the rest of the firmware). The electronic building blocks of the system are chosen to have a wide operating temperature range, making PANDA operates well in waters of different climate regions. A HD of 12 GB storage capacity is used for the data storage. Unfortunately, the MCU is only able to access the HD up to 8 GB in MSDOS compatible format. Because of the memory addressing limitation, it is accessed in the form of four partitions of 2 GB. This limitation is removed by writing the data to HD in raw format; the down side is that the user requires a special program to download and convert the data into PC compatible format for post processing. Although this method is not so convenient, it is used in our basic configuration to obtain large enough storage capacity.

B. The Self-surfacing Subsurface Buoy: An Integrated Electronic Housing

In search of an integrated pressure case, floatation buoy, release mechanism, and rope into a single, reliable, and shock proven system, we discovered the Fiobuoy®, a product from FioMarine Instrument Pte Ltd in Australia that is designed to serve as a simple, self-surfacing, submersible buoy. It is a timed-release buoy system that releases itself to the surface at the time programmed by its user. It is a self-contained system, with dedicated processor with Real Time Clock and battery that responds to a precise release event with little error. It has a typical accumulated tolerance of about 10 minutes per year, which means only a very small fractional tolerance exists if used at short-term deployments on the order of a few weeks.

We saw this buoy structure as a good starting point to develop our integrated system. What we needed was to find a way to incorporate our electronics into its rather limited internal space. We found that several modifications were needed to the original buoy design in order to meet our requirements for space, buoyancy and balance for smooth unraveling of the recovery line on release. These modifications increased the length of the useable internal cylindrical space. This space is used to house all the dry end electronics and battery pack. The battery pack occupies 60% of the available space, leaving sufficient length of available cylindrical space to mount the MCU board, hard disk storage, analog signal conditioning, digital to analog converter, and also other supporting circuits. The additional casing length also increases the buoyancy to carry the additional payload.

PANDA's release mechanism is a small but strong "jaw" that grips a bearing-ended stud tied to the end of the recovery line. During the release event, the jaw, driven by a high torque electrical motor, slowly opens, breaking away potential bio fouling that might have grown onto it during its stay underwater, making this a very reliable release mechanism. The release mechanism is shown in Fig.3.

Another good feature of this release mechanism is that it is a single piece, molded module. Therefore, PANDA has the minimum number of potential leakage joints a serviceable sub-sea electronics housing could have: one end-cap joint (for inserting the internal electronics). The wet end sensors are connected to the internal electronics through a single underwater bulkhead connector, which is molded onto the housing directly, thus posing minimum additional danger of flooding the PANDA. Although leakage is unlikely, PANDA is equipped with an internal leak detector that will trigger an immediate emergency-surfacing event once water is detected inside the housing, giving no time for the leakage to cause serious damage to the internal electronics. The PANDA housing is fitted with a standalone battery pack, that allows the timed-release circuitry to operate for at least 1 year. This circuitry has it's own microprocessor that releases automatically if the battery voltage falls below a pre-set threshold or if a leak is detected.

TABLE 1
OVERALL SPECIFICATION OF PANDA

Specification Parameter	*Min*	*Typical*	*Max*	*Unit*
Acoustic Acquisition bandwidth		**1**	**12.5**	**KHz**
Continuous Data Streaming to HD		**2**	**25**	**Ksps**
Operating Temperature	**0**		**+50**	**°C**
Operating Humidity	**0**		**95**	**%**
Average Overall Power Consumption running 20ksps data acquisition.		**2600**	**4100**	**MW**
Supply Voltage	**5**	**7.2**	**12**	**V**
Storage				
MSDOS compatible format			**8**	**GB**
Raw format			**HD size**	
Continues Data Recording (12bit data) time (7.2V, 232Wh battery pack @ 12GB HD)				
Sampling @ 2ksps *		**228**	**264**	**Hour**
Sampling @ 20ksps **	**57**	**90**	**110**	
Number of RS232 port	**1**		**6**	
Operating Depth	**4**	**100**	**200**	**Meter**

Currently the PANDA housing is equipped with sufficient cable to allowing it to operate at depths of up to 200 m. The overall system weight is about 30kg in air. The modified housing has approximately 5 kg of positive buoyancy when loaded with our standard electronics payload in seawater.

C. *Main Acquisition Electronics and Storage System*

The main data acquisition is powered by a microprocessor from Motorola, which has a processing power equivalent to that of an 80286 CPU, running at a speed of 2.5MIPS with a 16MHz processor clock. Its main task is to collect analog data, digitize them, and store them on an IDE hard disk in a predetermined format. With some hardware and software modifications, the system can be altered to provide more analog input channels with overall sampling rate limited to 25 ksps. Currently the system collects data from a single channel at 2 ksps. The system is equipped with one RS232 channel that can be used to communicate with sensors that provide serial digital reading. Future versions of PANDA could be designed to have additional data sampling channels and/or alternative sensors if required.

The Cornell analog signal conditioning consists of a sensor interface, a preamplifier, an 8th-order linear phase low pass filter, a gain stage, and a digital interface to MCU. The filter bandwidth is adjustable between 250 Hz and 2.5 kHz, while the gain can be set between 20 dB to 50 dB. The processing power of current microprocessor units is sufficient to simultaneously digitize and write perhaps 25 ksps worth of data onto hard disk. Currently an omni-directional hydrophone is attached to the only analog channel, from which the data is recorded on hard disk with overall adjustable sensitivity from –146 dBV re 1uPa to –116 dBV re 1μPa.

As the rest of the electronics are basically individual PCB mounted boards, the fragility of the hard disk is the limiting factor of the system reliability against mechanical shocks and vibration. A 2.5" laptop hard disk is chosen and preferred over others because of its high mechanical reliability. The hard disk is designed to work reliably under 175 G of shock impact and random vibration of 0.65 G, even more if the hard disk is not running.

A custom payload cage was developed to hold and secure these electronics, and a battery pack, in PANDA's internal space. To further improve the robustness of the system against shock and vibration, vibration-absorbing standoffs have been used to support critical electronics, see Fig. 4. This makes the system robust and well adapted to harsh environments. The cage is also designed to be able to carry different electronics configurations, allowing us to match the payload to our desirable system to performance, and to balance the system bandwidth, functionality and

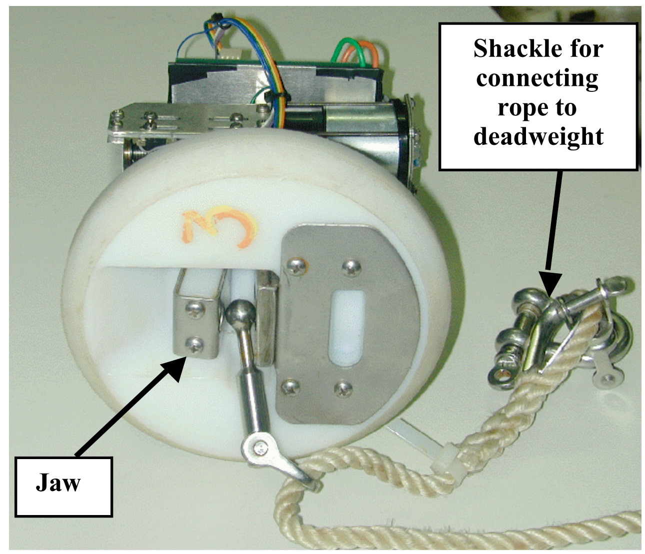

Fig. 3. Fiobuoy® Release mechanism

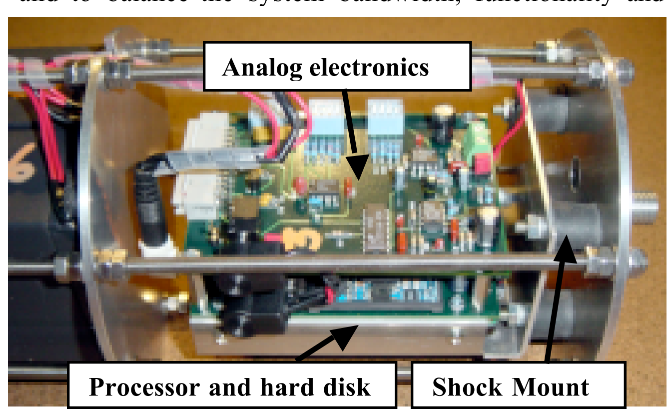

Fig. 4. Acoustic data acquisition electronics, provided by Cornell Ornithology Laboratory.

battery life. The payload is kept as near to the cylindrical axis of the internal space as possible. This maximises the likelihood of PANDA un-winding itself smoothly when surfacing, avoiding undesired oscillations that might decrease system reliability.

High energy density batteries are needed to provide maximum power to the system, while leaving maximum space for the electronics. Six "off the shelf" rechargeable Li-Ion video camera batteries are combined into a single battery pack lasting the electronics to run for hundreds of hours in the case of sampling at 2 kHz. Li-Ion batteries are chosen because they are one of the highest power density and weight performance battery commonly available at reasonable cost. For the current system, system power is mainly consumed by the PC compatible IDE hard disk drive used for data storage. This indirectly causes the battery life to be determined by the data acquisition rate, which determines how frequently the hard disk will be accessed. Although the self-release buoy system can support up to 1 year of operation on average, the battery supports continuous data acquisition over a maximum of about 12 days. Increasing the sampling frequency or number of channels would decrease the endurance.

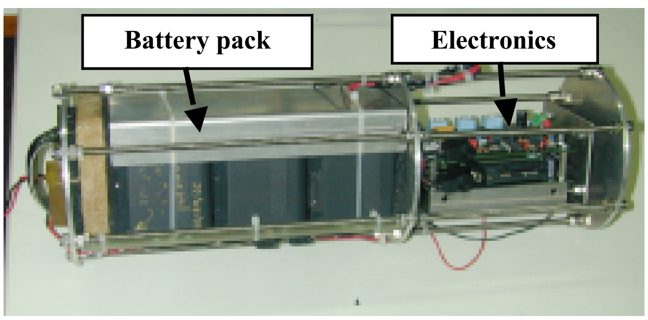

Fig. 5. Internal mounting cage holding Lithium Ion battery pack and electronics.

The current version of PANDA is being used in several local and international collaborative efforts to collect ambient noise data and acoustic transmission loss data from deterministic sources. Recently, four PANDAs were deployed in the ASIAEX 2001 experiment in the South China Sea. ASIAEX 2001 was conducted jointly by researchers from seven nations including the USA, Taiwan, China and Singapore. Unfortunately, only one of the four deployed PANDA's was recovered. The loss of the other three is attributed to the comparatively deep water (in one case just over 200 m), the hostile environment caused by intensive fishing activity (including bottom-trawling) and high currents (sometimes in excess of 5 kts) that can drag a small surface float below the waves.

III. SAMPLE DATA FROM PANDA

Fig. 6 shows a 10 second data clip collected in the ASIAEX 2001 experiment. The peak signal strength occupied nearly 50% of the total dynamic range, which leaves some head room for a possible large transient. Some active FM sweep sources used in the experiment are clearly seen in the spectrogram, as are intense low-frequency tonals and 'pink' noise from shipping.

IV. PLANNED SYSTEM EXPANSION

To increase the functionality, ARL is planning to increase the number of sensors on the standard system. At the same time we will stress the flexibility of adding or replacing optional sensors to support different research areas. Fig. 7 shows an overall system block diagram Thick boxes indicate modules that are currently implemented; Shaded boxes in the diagram are the ones to be added in future; and the thin boxes are those that are optional.

While the current system is released on a schedule determined by a pre-programmed timer, it is possible to add a standard shallow-water acoustic release below the PANDA standard package if one is prepared to use a disposable deadweight as the anchor.

A small, self-contained, external CTD data logger and/or sound velocity sensor are planned as new add-ons to the standard system. With the combined recordings of conductivity, temperature, pressure, sound velocity, and acoustic signals in a single integrated and compact system, PANDA will be very useful for shallow-water physical oceanographic studies.

Nevertheless, the system is not limited to the above configuration. The ARL has machined and mounted an acoustically transparent mast at the end cap opposite the release control, on which various sensors could be mounted.

Since the mast is located on the cylindrical axis, self-contained sensors can be mounted on it with minimum effect on the surfacing operation. Positioning is important because external off-axis components create a considerable asymmetric drag that can cause rotational instabilities when the PANDA is unraveling its recovery line, leading to the risk of entanglement. For sensors that need to be wired to dry end electronics inside PANDA, there is a single submarine connector with multiple pin outs, providing interconnection between the sensor and the internal space.

Several sensors useful for local biological work, such as a turbidity sensor and flourometer, are being identified and could be integrated into PANDA to provide a configuration suitable for scientific research works in marine coastal biology in general.

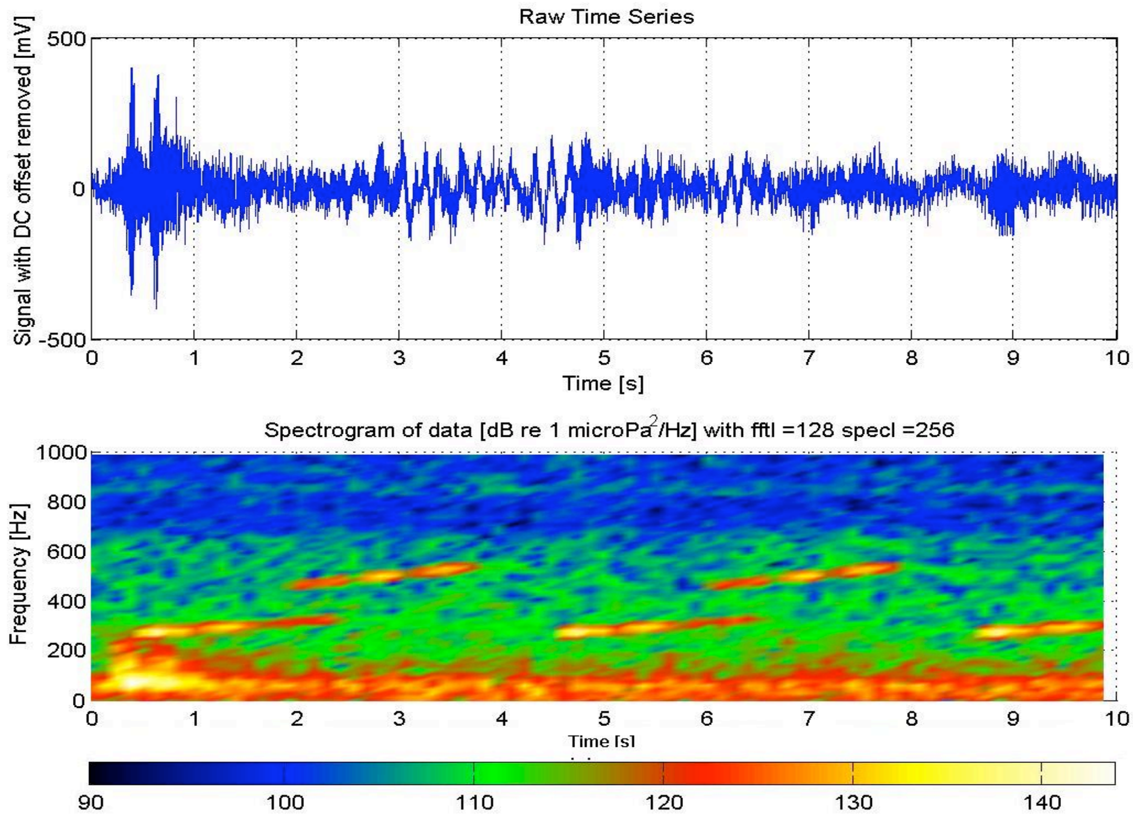

Fig. 6. Time series and spectrogram of sample data from South China Sea.

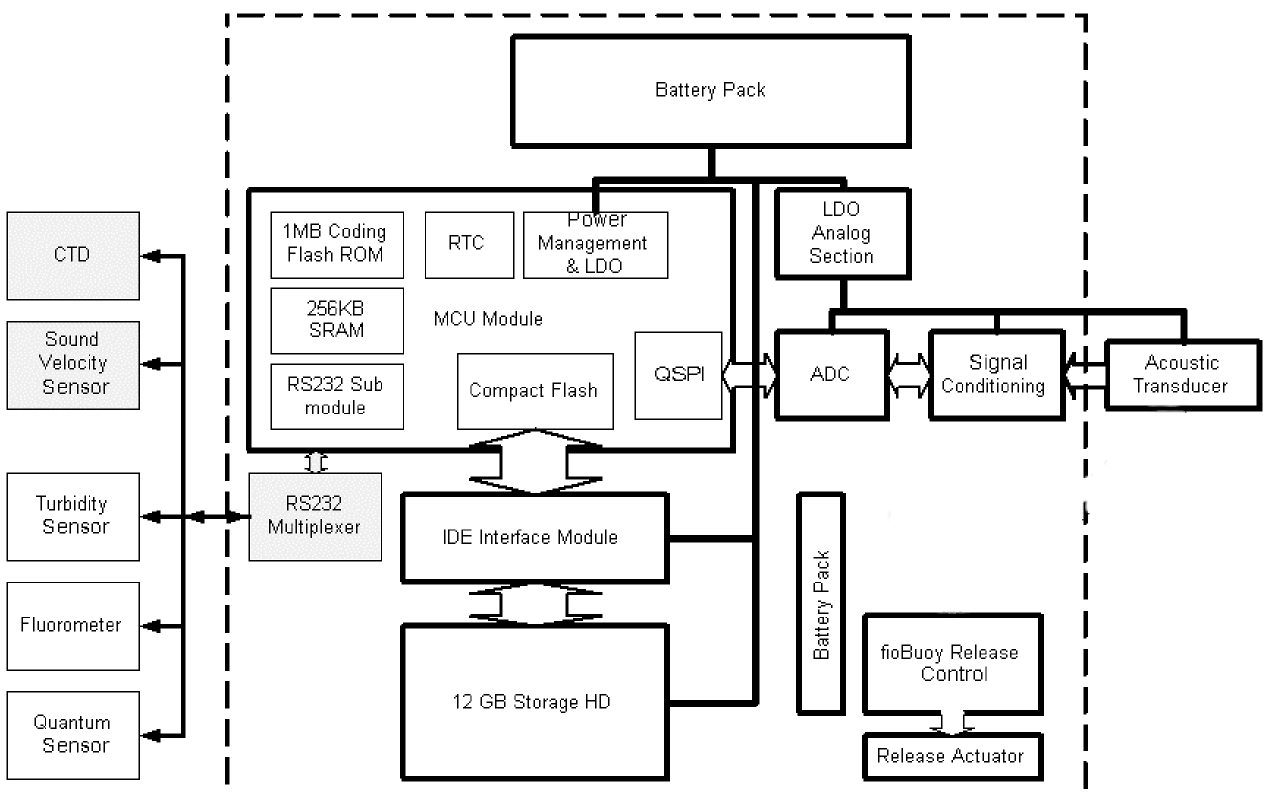

Fig. 7. System block diagram.

If desired, some fast response sensors, such as those from PME, can also be integrated, allowing PANDA to perform simple water column profiling of conductivity, temperature, fluorescence and turbidity when traveling vertically during deployment and recovery process.

V. CONCLUSION

ARL has successfully developed an inexpensive, lightweight, robust, self-contained and highly integrated bottom mounted data acquisition system that is suitable, but not limited, to be used as an acoustic logger. The design consists only of two separate parts, an integrated buoyancy flotation unit that combines pressure casing, electronics payload, release mechanism and spooled line unit, and a separate anchor. Compared to conventional systems that have all of these in separate modules, and therefore are relatively complicated to handle, PANDA is a system that can be deployed and recovered easily by only two persons and moreover, from a small vessel without specialised equipment. ARL has also designed PANDA so that it is flexible in mixing electronics payloads both in a modular cage inside the system and external mounting around a supporting mast. All the above features greatly facilitate rapid and affordable data acquisition, reducing experiment lead-time and cost.

The system has been successfully deployed in depths of 17-100m, both in international and local experiments, acquiring useful ambient acoustic noise data and monitoring oceanographic acoustic sources.

Acknowledgements

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