Advanced PANDA for high speed autonomous ambient noise data collection and boat tracking – system and results

Teong Beng Koay, Paul James Seeking, Mandar Chitre, Soo Pieng Tan, and Matthias Hoffmann-Kuhnt

Acoustic Research Laboratory, Tropical Marine Science Institute,
National University of Singapore, 12a Kent Ridge Road, Singapore 119223.
koay@arl.nus.edu.sg, paul@arl.nus.edu.sg

Abstract - **Many underwater acoustic recording applications require a high speed data acquisition system that is not contaminated by noise from the support vessel. This calls for autonomous recording system that is self-contained. Many of such systems are either bulky in size such as moored data buoy, or conventional bottom mounted system with acoustic release system; small in data capacity such as miniature acoustic recorder or tags; or needs high maintenance costs such as AUV monitoring. We present an alternative autonomous system that is cost effective, small and provides directivity capability.**

The Advanced Pop-up Ambient Noise Data Acquisition (A-PANDA) is the next generation underwater acoustic recording system developed by the ARL. The system now has increased CPU power, enhanced sampling rate, increased numbers of channels, digital control, oven controlled real time clock, compass, and highly programmable through a homebuilt trusted-real-time scheduler. Each A-PANDA has enough data storage and battery capacity to allow deployment periods from tens of hours of continuous recording, to weeks of burst recording. System retrieval can be easily performed through an acoustic release or a pre-programmed time release. A-PANDA can be fully recovered and leaves no anchor or deadweight behind, introducing minimum or no environmental impact to the site of study. A typical deployment procedure involves a small vessel ferrying the A-PANDA to a desired location, deploying the system, leaving the vicinity and returns only for retrieval; hence the acoustic recording is free of self-contamination from the surface vessel.

We present work on the use of the A-PANDA to form a random array for the purpose of tracking surface vessels. Since each A-PANDA has a triangular array with three hydrophones, our approach uses high resolution techniques such as the MUSIC algorithm to provide DOA estimations to targets from each A-PANDA. Localization can be achieved by combining the DOA estimations for all of the A-PANDAs. The developed algorithm makes use of cosine packet transforms to identify likely tonal content from surface vessels, prior to MUSIC beamforming, such that only chosen frequencies are beamformed. This reduces the computation, and reduces the clutter in the beamformer output. Finally a Myriad filter is used to track the output of the beamformer over time. When compared against a model based Kalman filter the Myriad filter requires no dynamic model of the surface vessel, and does not have a tracking lag. Simulation results and field trial results to test the DOA estimation performance of a single A-PANDA show a promising tracking performance with an average bearing error of 2 degrees. The maximum range was limited to 650m due to physical constraints.

I. INTRODUCTION

Developing a system to detect, classify and track multiple targets in shallow water is a complex and challenging problem. Channel multi-path, fast varying channel characteristic, signal contamination from biological and man-made noise taxes the complexity of the signal processing. From the aspect of physical system, deploying moored acoustic recording systems are less of a desirable in shallow water due to their large size and logistic requirement. Hence a compact, highly integrated acquisition system yet with sufficient processing power would be preferred.

We propose to deploy an array of compact and highly integrated data acquisition node for such purpose. Each individual node is equipped with the capability to estimate Direction Of Arrival (DOA) to multiple targets within the near-field proximity of the array position. While targets are in the far-field, multiple of these DOA estimations can be averaged to give a more accurate estimate.

The Acoustic Research Laboratory (ARL) has developed an autonomous, highly integrated ambient noise data collections system, Pop-up Ambient Noise Data Acquisition (PANDA), and has been upgrading it in the pass years [1, 2]. The system has been used for ambient noise studies and acoustic related experiments in Singapore local waters and South China Sea [3, 4, 5]. We upgraded the design to realize Advance-PANDA (A-PANDA) with increased processing power and data acquisition speed in order to increase the number of acquisition channels from one to three. The new system inherits features from its earlier versions which includes a compact size, fully autonomous, self-contained and highly integrated. It presents no surface expression when deployed. A-PANDA can be pre-programmed for missions with various parameters such as deployment period, acquisition modes that can either be continuous or scheduled of burst acquisitions, and the bandwidth and gain of the analogue input channels. Each A-PANDA is fitted with three

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hydrophones in a triangular array, which is used to detect and estimate the DOA of targets.

This paper will illustrate the design of the A-PANDA, the algorithm used for detecting, DOA estimation and tracking of a boat, and presents preliminary boat tracking result using a single triangular array deployed from a pier.

II. A-PANDA DESIGN

The main design criteria of PANDA are to produce an autonomous recording system that is self-contained, compact, no surface expression when deployed, highly integrated and deployable from small boat. A-PANDA maintains all these features but carries more processing power, data acquisition speed, number of channels, enhance analogue channel with controls, orientation measurements, and acoustic links.

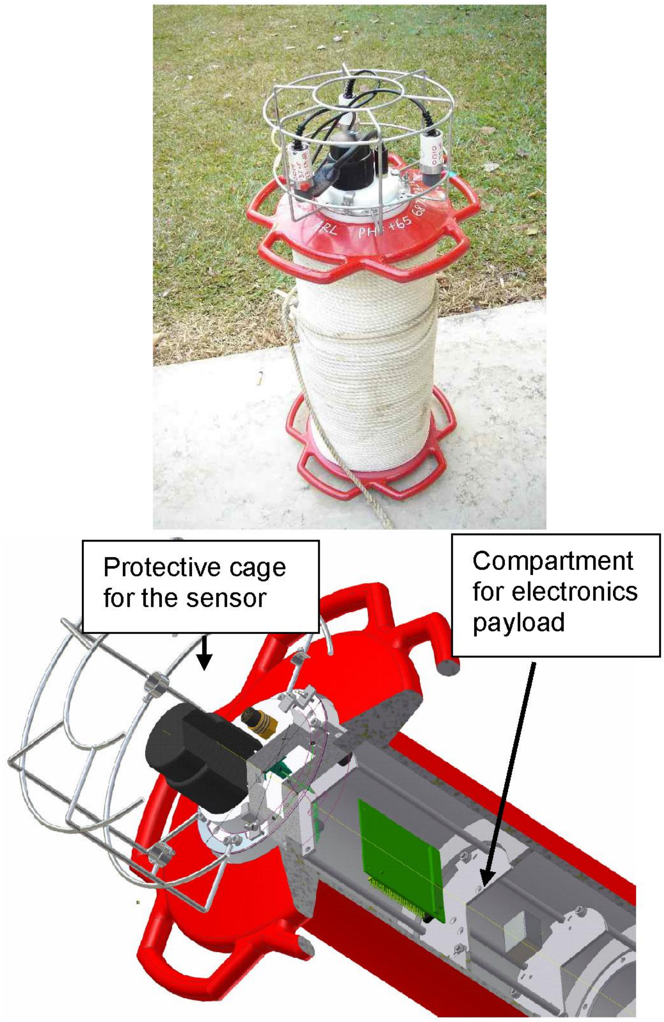

Fig. 1: Section drawing and picture of a A-PANDA assembled

After completion of assembly, the system appeared as a cable drum, which is a cylindrical buoy with overall size of 30cm diameter by 70cm long. A protective cage is then mounted on top of the buoy to protect the sensors, see Fig. 1. The buoy can be spooled with nylon rope up to 200m long, on which an anchor is attached at its free end. A retention pin is located on the rope at 1m from the anchor towards the direction of the buoy, which in turn held in place by a release mechanism on an end-cap at one end of the buoy. When the release mechanism is closed, it prevents the rope from un-spooling as long as it is held in tension. The entire acquisition electronics payload and power source are mounted on another end-cap that is screwed into the opposite end of the buoy. The centre of the buoy is a watertight compartment where the acquisition electronics and the release mechanism electronics are housed in, see Fig. 1. This makes it a highly integrated system where release mechanism, electronics and sensor payload, buoyancy unit and release line are all in single aperture.

The electronics payload end-cap consists of two enclosures: The first payload cap that screws directly into the buoy, where it hold the electronics on one side and made various electronic signal available on the other side via a 100-pin connector. The second is a smaller sensor cap that recessed and seals on the first; it is where all the acoustic sensors are mounted on; see Fig. 2. With this is design, only the sensor cap needs to be opened after each deployment to access the data, charge the batteries and service the electronics firmware; keeping the main electronics payload sealed and un-exposed to corrosive environment. This shall greatly enhance the reliability, robustness and durability of the payload.

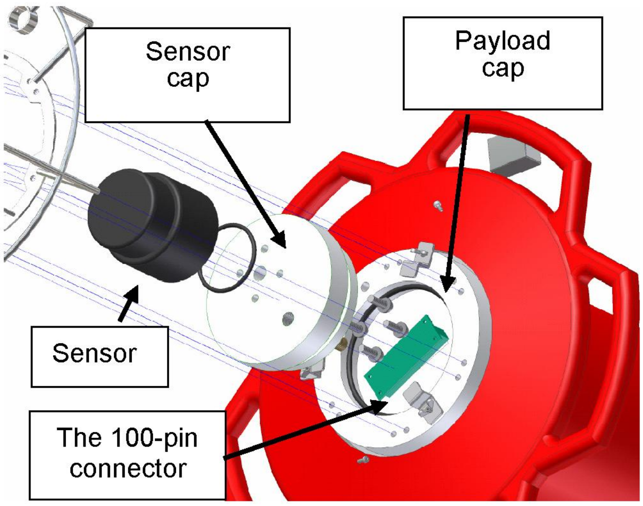

Fig. 2: Stages of the payload end cap

The system is deployed by dropping off from the side of a vessel to have it sink freely to seabed by the anchor's weight. One of the system design challenges is for it to survive the significant mechanical impact when system lands on the seabed. Electronics components with high shock and vibration ratings are chosen for this application. Shock and vibration absorbents are also introduced between the electronics payload and the physical buoy to minimize the impact to the payload. Electro-mechanical components are scheduled to shutdown during this period and only being powered up once it is on the seabed.

The electronics payload comprises of Independent Functional Modules (IFM) that can be physically included or excluded as needed. Most of the IFM can also be digitally shutdown when not in used. The modules include main acquisition-processing system, analogue module, power management module, acoustic link, orientation sensor, and a co-processor with high precision clock. The overall conceptual design is given by the block diagram in Fig. 3. The Oval block denotes the signals made available to the 100-pin connector block and the square block represents the electronics modules.

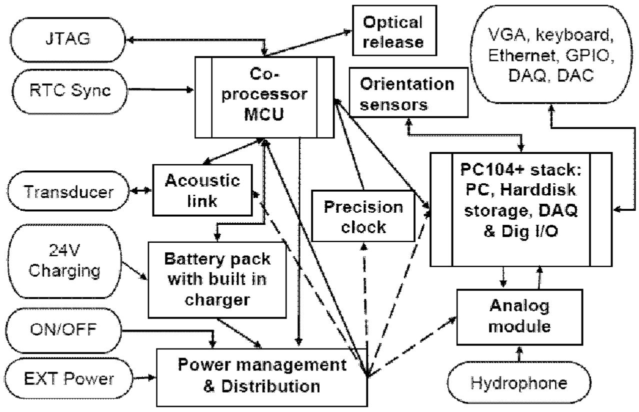

Fig. 3: Simplified block diagram of A-PANDA electronics

A. Main acquisition-processing module

The main processing power and data acquisition of the system is provided by PC104+ stack that consist of an Intel Pentium III based industrial PC, a 40GB harddisk and a PC104 data acquisition (DAQ) module. We configured the stack to acquire up to 12 Single-Ended (SE) channels or 6 Differential-Input (DI) channels with maximum aggregated acquisition rate of 200ksps at 16-bit resolution. The DAQ module provides auto-calibration for analog input channels which could be used to calibrate the signal path should temperature variations become significant. We also made available a number of digital I/O for general purpose usage. For the purpose of this project, however, we only interface three of the available analogue channels to our analogue module and setup each channels to acquire at 60ksps, giving us up to 30 kHz bandwidth on each channel. The 40GB storage will give us some 33 hours worth of data storage capacity at this rate; longer if the sampling rate and/or number of channels are reduced.

The PC104+ stack provides standard interconnectivity to the system such as Ethernet, RS232, video and keyboard outputs. The first two are used during normal operations while the later two was used during system development and debug stages. All these are made available to the 100-pin connector block accept the RS232 signals, which are used to communicate with the co-processor and orientation sensors. The industrial PC serves as a main coordinator for all the DAQ missions and provides a command shell for user interface; details will be presented in section III. It also communicates with the co-processor unit through RS232 in order to control the IFMs.

B. Co-processor module with precision clock for peripheral control

The co-processor module is a MSP430 MCU that serves as central control of the functionality of most peripheral modules. User could communicate to the co-processor unit through PC104+ (using Ethernet) in air, or through acoustic link in water. It also serves as communications gateway between PC104+ stack and acoustic link accept the commands to control the IFM. This makes sure that user could still control the IFMs and more importantly initiate a release sequence in the event that PC104+ stack is inoperative (e.g. commanded to shutdown when battery power is too low). The co-processor is also the module that controls an optical release link that triggers the release mechanism electronics package secured at the other end of the buoy.

In order to take advantage of tracking targets using multiple A-PANDA, data samples need to be accurately synchronized. Since each A-PANDA is independent, the data in each PANDA is time stamped in order to realign them. General real time clock (RTC) used in PC provides accuracy of ±5ppm at 25°C, which translates to about ±0.43 seconds or ±663m distance measurements tolerance over a day in water with sound velocity of 1542m/s. This is insufficient for us application. In order to overcome this issue, we installed a 10MHz Oven Controlled Crystal Oscillator (OCXO). The output pulse rate is stepped down by 256 times using an 8 bit counter, which is then fed into the co-processor to produce a 48-bit timestamp. In the event of array operation, A-PANDA units will be clock-synchronized prior to deployment. PC104+ stacks will regularly interrupts the co-processor for the precision timestamp and record them along with the acquired acoustic data. This produces data synchronization to ±0.32ms (or ±0.5m accuracy) over a day, which is more than 1000 times more accurate. The cost for this high precision clock is higher power consumption required by the oven.

C. Analog module, hydrophones and orientation sensor

The analog module contains linear regulators for bipolar signal conditionings circuitries that can be controlled digitally by the GPIO pins from PC104+ stack. In combination of the DAQ modules and analog modules' programmable gain, users are able to set gains between 0 to 82dB, and anti-aliasing filter's 3dB cut off frequency from 10 kHz to 150 kHz in 10 kHz steps. This allows the user to digitally set the acquisition rate freely without having to worry about aliasing of the signal as well as optimizing the dynamic range of acquisition.

Three hydrophones arranged in a triangular array are then connected to the analogue module. Each of hydrophones is a piezo-electric sensor with -192dBV re 1μPa sensitivity that we integrated and potted a first stage amplifier of 25dB gain at the back of it. A preliminary test in ARL's fresh water tank estimated that the self-noise was equivalent of about 47dB re 1uPa/√Hz. Since there was no shielding, nor the tank was an anechoic facility, we expect the actual self-noise to be smaller than the result of the experiment.

When deployed, A-PANDA is anchored and held in upright orientation only by its own buoyancy [2]. The hydrophones are assumed to be in the plane parallel to the sea surface when performing DOA estimations. When there is strong current, however, it will be subjected to swings and rotations. Hence it is important to detect the orientation changes and correct for it to maintain the accuracy of localizing a particular sound source. An integrated digital compass with pitch and roll sensors is used to provide orientation information such as pitch, roll, and bearing. The module provides heading accuracy of better than 0.5° when operate within ±80° dip angle and ±40° tilt angles, while pitch and roll accuracy is 0.2° within ±40° operating range. The orientation sensor is attached between the electronics payload end-cap and the payload in such a way that it remains in a fixed location in reference to the mountings of the three hydrophones.

D. Power management module and battery pack

A power management module is implemented in this design to generate and distribute different supply voltages required by IFMs from a single battery pack. Power supplies to IFMs can also be switched off with controls from co-processor as indicated by dotted lines in Fig. 3. A set of commands to the co-processor can be sent from either PC104+ stack or acoustic link for this purpose. During an acquisition mission, industrial PC could request the co-processor to shut down the entire PC104+ stack along with any IFMs for a period of time to conserve energy. The power management module provides an external power port, which it will automatically switch to when a 12~24V DC supply is present at the port. When system is in storage, a digital switch is provided at the 100-pin connector that can be used to shutdown the main DC/DC regulator in this module; draining only quiescent current of micro-amps of power.

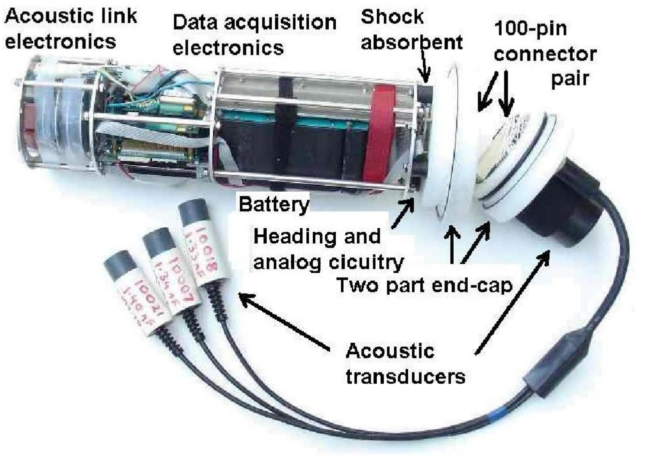

Fig. 4: Electronics payload with sensors

The increased processing power, acquisition rate and precision clock put a tax to the power budget of the system. Current prototype battery package provides 177Wh energy, a fully charged battery pack will last us a little over 10 hours of continuous recording with all IFM switched on. We have prototyped and are currently testing a new set of custom Li-Ion battery pack. The prototype will provide some 570Wh of energy that will power a fully switched on system for 35 hours of continuous recording. Each of the prototype battery pack has a built in full featured Li-Ion battery charger that will automatically charge the battery when a 24VDC is provided at charger port. It also provides a communication protocol for the co-processor to investigate the available energy in order to switch to emergency power down modes when necessary, where only essential electronics are kept on. At the extreme case, only co-processor and acoustic link are kept on, consuming about 12% of full power consumption. Fig. 4 shows a full assembly of the payload.

III. FUTZ – MULTITASKING OPERATING ENVIRONMENT RUNNING ON DOS

We aim at using a simple, reliable, small footprint Operating System (OS) that allows us to directly access the hardware in our PC104+ stack. We chose to use DOS due to its speed and cost effectiveness on top of the advantages listed earlier. Its primary drawback is that it is a single tasking OS. In A-PANDA implementation, we need a multi-tasking OS. We decided to develop an operating environment (which we named it Futz) that runs on top of DOS to provide us multitasking support.

Accessing more than 640 KB of memory and large hard-disks in DOS can be difficult. In order to overcome this, we use DOS Protected Mode Interface (DPMI), a well tested and supported programming API widely used in DOS-based games, to provide us a flat 4 GB addressing space. In order to access disk space larger than 4 GB, we switch to FreeDOS, one of DOS variants that support large hard-disks. The A-PANDA software that performs tasks in deployment missions runs under Futz, which runs on top of FreeDOS and DJGPP DPMI.

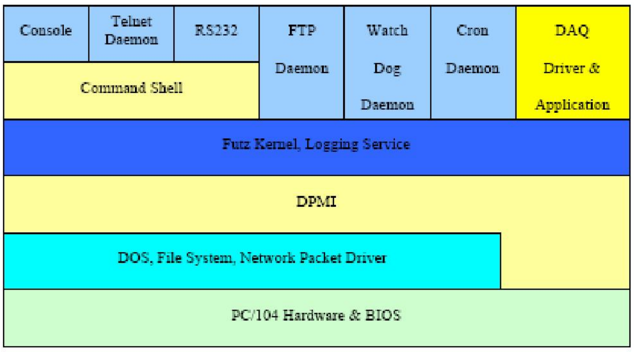

Fig. 5: Futz block diagram

Futz is an operating environment that provides non-preemptive multi-tasking services such as scheduling, message passing and timers for the A-PANDA software. Additionally, it provides commonly needed software components like a command shell, RS232 terminal shell, telnet shell, a FTP service, task scheduler (cron), event logging service, power management and a watch-dog timer (which our PC104+ stack supports). It uses available DOS drivers such as network packet drivers (Crynwr) and WATCOM TCP/IP stack to provide Ethernet connectivity.

Futz drivers have been developed for the DAQ module to enable the A-PANDA to acquire and record data on the hard disk. Due to limitations of file size, file rotation has been implemented in the DAQ driver to start a new file after every 1 GB of recording. A software block diagram of Futz is shown in Fig. 5

Futz is a non-preemptive (or cooperative) multitasking system, i.e. the tasks under Futz have to give up their time slices voluntarily in order for Futz to function properly. The application structure is based on a message-passing paradigm (similar to Windows). Each task has a message handler which receives messages when events occur. The task processes the event and then returns control to the kernel for further event processing. The console, telnet and RS232 tasks provide access to a command processor, which acts as the primary user interface for Futz. Futz commands can be stored in "batch" files with extension "ftz" and executed from the command line or scheduled for automated execution using the crond. The ftpd provides a network interface to download or upload files from the A-PANDA. Logs are written to a file as a record of events happened during a mission.

IV. MUSIC ALGORITHM

MUSIC or MUltiple SIgnal Classification was first proposed by Schmidt [6] as a high resolution spectral estimation technique. It is used in beamformers to estimate the spatial spectrum, i.e. Energy over bearing. It is not a true spectrum; peaks in the spectrum can be well defined and useful in locating the DOA of a target. The amplitude of such peaks does not directly correspond to the energy in the signal coming from a particular DOA.

In conventional frequency domain beamforming, array data for a given frequency bin is phase shifted by a steering vector and the summed to give the energy coming from each direction. This is based on the assumption that the shifted and summed data will be at a maximum in the direction of the target since the data from each hydrophone will add up constructively. That is, signals coming from directions other than that of the target are uncorrelated across the sensors in the array. In the direction of the target, signals are correlated (with zero lag) across the sensors and hence add constructively.

The narrow band MUSIC beamformer makes the assumption that the steered received data in directions other than that of the target are uncorrelated across the sensors in the array.

The narrow band correlation matrix of the array of the sensors is calculated at a given frequency. Eigenvalue decomposition is the performed on the correlation matrix and the correlation matrix is reconstructed from the N-T eigenvectors, where N is the number of sensors, which corresponds to the N-T smallest eigenvalues. T is taken as the number of target signals, this is generally unknown, but can be estimated from the eigenvalues given an ambient noise sample.

Reconstructing the correlation matrix from the smallest N-T eigenvectors removes the target signal from the correlation matrix leaving the noise subspace. The signal and the noise subspace should be orthogonal to each other. A search is carried out over directions to find bearings for which the steering vectors are orthogonal to the noise subspace. This search can be analytically formulated and solved to give the DOA(s) (Root-Music [7]), or can simply by calculated for each bearing. The second method is essentially conventional beamforming using the noise subspace i.e. for a particular direction a steering vector is calculated, and multiplied by the (reduced) correlation matrix. The resulting spectrum is a constant value in all directions other than the target direction where it drops to zero. The spectrum is inverted

(1/Spectrum), giving peaks at a target location which tend to infinity. Due to the scaling difference between the amplitude of the peaks and the angular bin size, the peak appears to be very narrow.

Let the time-series received on the nth hydrophone of an N hydrophone array be denoted by $S(t,n)$, then the discrete Fourier transform of the a time series results in

$$S(\omega,n) = DFT\{S(t,n)\} \quad (1)$$

The N x N correlation matrix for a given frequency ω_c is given by

$$R_{ss}(\omega_c) = S(\omega_c,n)^H S(\omega_c,n) \quad (2)$$

The eigenvalue decomposition is taken of $R_{ss}(\omega_c)$, and is reconstructed from the eigenvectors corresponding to the N-T smallest eigenvalues giving $\overline{R}_{ss}(\omega)$.

To test the orthogonality of the steering vectors with the noise subspace that follow test is carried out for each θ.

$$A(\theta,\omega_c)^H \overline{R}_{ss}(\omega) A(\theta,\omega_c) \quad (3)$$

Where $A(\theta,\omega_c)$ is the steering vector for the array for a particular angle and frequency.

For a triangular array steering vector is given by

$$A(\theta,\omega_c) = \frac{\omega_c}{C}\mathrm{Re}\left[re^{-\frac{i2\pi n}{N}+\theta} \right] \quad (4)$$

where N is the number of hydrophones and n=1,2,..,N. r is distance from the centre of the array to each hydrophone in metres of triangular array. C is the sound speed in metres per second.

Clearly when the steering vector is orthogonal with the noise sub-space,

$$A(\theta,\omega_c)^H \overline{R}_{ss}(\omega) A(\theta,\omega_c) = 0 \quad (5)$$

hence the spatial spectrum is given by

$$P(\theta,\omega_c) = \frac{1}{A(\theta,\omega_c)^H \overline{R}_{ss}(\omega_c) A(\theta,\omega_c)} \quad (6)$$

The spatial spectrum will have peaks tending to infinity at bearings corresponding to a target.

The beamformer output, shown later is the average across frequency in (6). The DOA at which the maximum occurs is that of the target

V. TRACKING ALGORITHM

Fig. 6 shows the processing scheme that was implemented for the purpose of tracking boats. It is similar to a processing scheme in found in [8], which was tracking ground vehicles in air using a circular array of microphones.

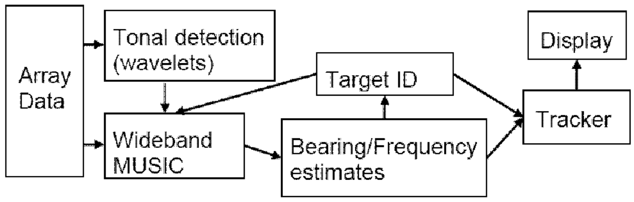

Fig. 6: Proposed signal processing scheme

Array data is the time series of each hydrophone, which is split into windows, the length of which corresponds to the number of the FFT points used in subsequent processing.

Tonals are detected by using a similar algorithm to Cosine packet transform tonal extraction technique in wavelet denoising tool box [9]. For each channel of the time series, a two level cosine packet transform is performed; dot product is then performed between first and second packets on the second level. This effectively picks out frequencies which are in the first and second half of the time window (Tonal). Another dot-product is performed with the result from each channel, such that the tonals that occur on all of the channels are picked out. This requires that the sensors are reasonably close together such that the frequency content on each sensor channels is spatially coherent. To detect peaks in the spectrum, a threshold has to be applied. The threshold can be either based on the energy on spectrum, or ambient noise spectrum, assuming that an ambient noise sample can be obtained.

After the tonal has been detected, a wideband MUSIC beamforming is carried out, by the repeating the Narrowband process on all frequency bands of interest given by the tonal detection stage, ω_c in equation (2). They are variants such as the steered correlation matrix technique [8], which give a single spatial spectrum over the range of bearings. However for the purposes of separating and identifying targets a bearing/frequency spectrum is preferred.

In the case of narrow band, if the number of targets is known or can be reliably estimated, the correlation matrix reduction step can be used to separate N-T > 1 targets. In the case of A-PANDA, N=3, so we can separate a maximum of two targets. In the case of wide band, targets can be separated on the basis of the frequency/DOA, providing that different targets have different frequency content. In the case of boats, their spectrum depends on the type of boat and its speed. Given a high enough frequency resolution, multiple boats can be resolved by identifying peaks in the mean of the bearing/frequency spectrum over frequency. The frequency content of each target can then be extracted at each target DOA from the bearing/frequency spectrum.

In this paper, we assume that there is only one target, so this stage of processing is not currently utilized. Multiple targets should be identifiable by their DOA clustering over time and by their frequency content over time. Methods such at K-means clustering or a simple neural network may prove useful in this respect.

Once the DOA estimates are calculated over time and identified, we process them to track the target over time. The standard method is to implement a Kalman filter, which given assumptions about the maximum rate of the change of target bearing that is expected, will attempt to provide a smooth curve representing the track. Kalman filters assume a Gaussian noise distribution.

The state variables are the bearing and the rate of change of bearing:

$$x(t) = \begin{bmatrix} \theta(t) \\ \dfrac{d\theta(t)}{dt} \end{bmatrix} \quad (7)$$

The state model for the boats bearing and change in bearing is given by

$$x(t+1) = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} x(t) + p(t) \quad (8)$$

where,

$p(t)$ is the process noise.

The measurement model is given by

$$z(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} x(t) + r(t) \quad (9)$$

where,

$r(t)$ is the measurement noise.

For comparison, a Myriad filter [10] was also implemented. This a non-linear filter, which will attempt to remove the impulsive noise from a set of data. It stems from work on symmetric alpha stable distribution (SαS). The working parameters are the expected variance of the noise, and degree of impulsiveness, both these terms are defined slightly differently in the SαS distributions compared with Gaussian statistics.

Currently the beamformer output (bearing against time) is plotted as a color map image. A separate graph shows the tracked output.

VI. RESULTS FROM FIELD TRIAL

A field trial was conducted early in the programme while A-PANDA's were still being built. The same external cage to be used in A-PANDA was mounted on pole and the same hydrophones were attached to the cage, forming a triangular array with an inter-hydrophone spacing of 0.21 m. The $\lambda/2$ spacing of this array corresponds to a maximum working frequency of 3.7 kHz. The data was acquired at a rate of 12000 samples per second, which are slower than the A-PANDA's maximum sampling rate per channel. The pole mounted hydrophones were deployed from a jetty, with a boat running on an arbitrary route. The schematic of the experiment is shown in Fig. 7. Fig. 8 shows the pole mounted hydrophone cage, and its mounted position on the jetty.

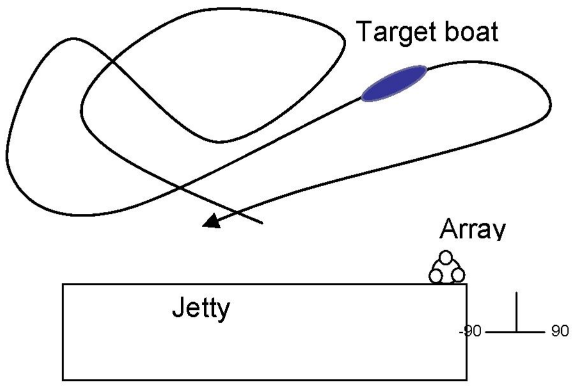

Fig. 7: Experiment configuration

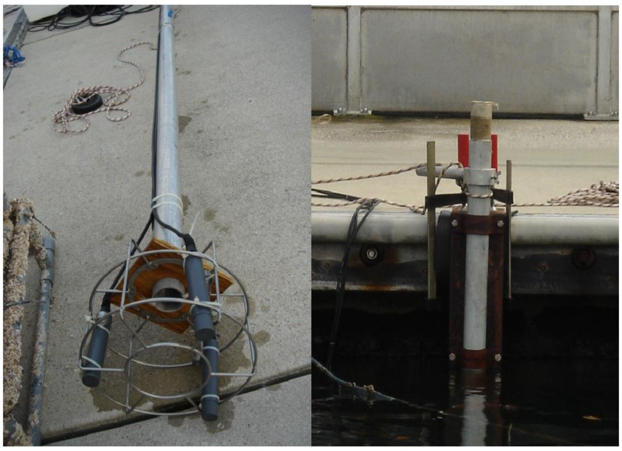

Fig. 8: Pole mounted hydrophone cage and mounted position on the jetty.

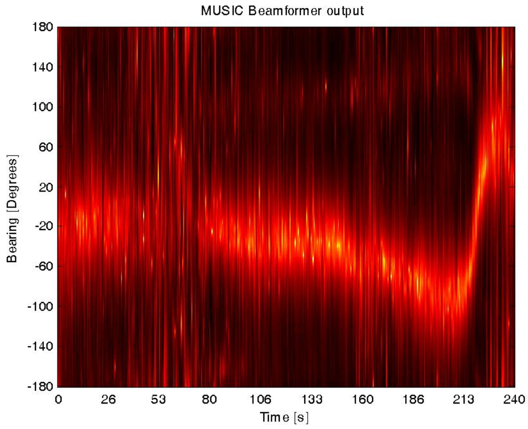

Fig. 10 Output from MUSIC beamformer

The boat was equipped with a GPS tracking system such that the position is logged. For the results presented here the boat made a random course up to a maximum speed of 20 knots. The speed and range over the 240 second recording is shown in Fig. 9.

Fig. 10 shows the output of the MUSIC beamformer, the boat track can be clearly be seen, as the orange/red band across the middle. The maximum value at each time slice is found to give the DOA of Whitetip at that time slice. These values are plotted on as red dots in Fig. 11. These raw DOA estimates are significantly subject to noise especially 50 to 100 seconds. It is suspect that this is due to the vibration noise of the pontoon (where the array strapped to) is braising against the pillar of the jetty.

By applying the tracking filters the noisy DOA estimates can yield a smooth track. Results for the Kalman and Myriad filter are shown in Fig. 11 as estimated tracks. The Myriad filter outperforms the Kalman filter. The bearing error is shown in Fig. 12.

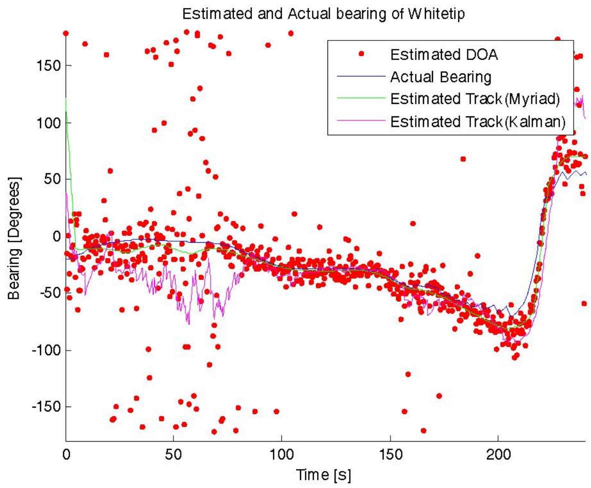

Fig. 11: Estimated DOA and tracked output

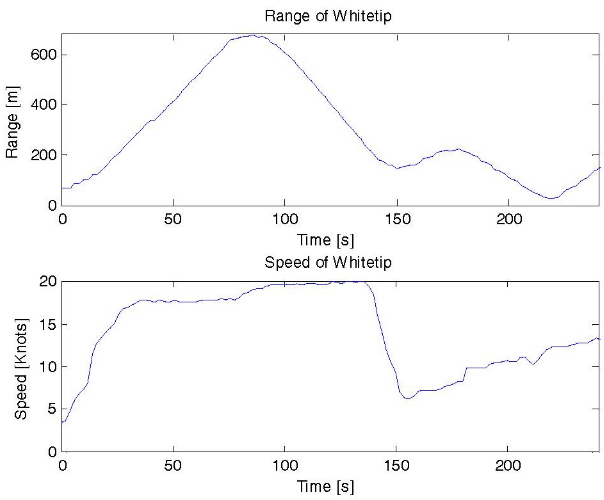

Fig. 9: Range and speed of the target boat - 'Whitetip'

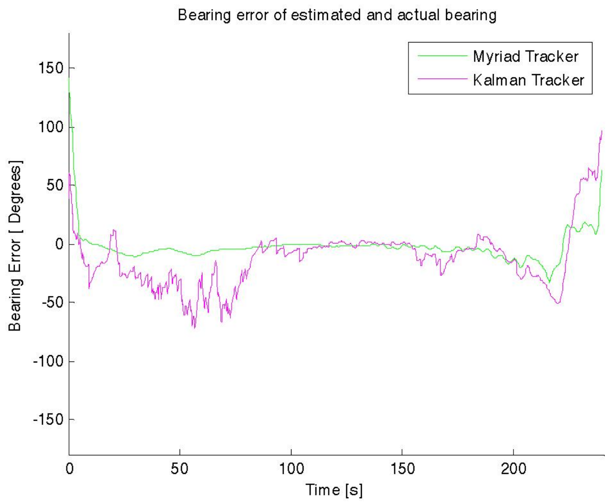

Fig. 12: Bearing error of the Kalman and Myriad tracking methods.

VII. CONCLUSIONS

We presented a prototype system that has been designed with the capability to perform boat tracking. The system is highly integrated and compact (ϕ30cmx70cm long). It provides enough processing power and data capacity to perform acoustic acquisition at aggregate of 200ksps for 35hours. Another feature of the prototype is that it presents no surface expression and hence does not hinder normal boat traffic. It could also perform multiple-tasks such as direction logging, data acquisition, time-stamping etc. that are pre-programmed by the user, even for them to run at the same time.

The results of the field trial show that the track of the boat is clearly defined in the beamformer output, even at the maximum range. The tonal extraction algorithm works to pick out the tonals corresponding to the boat. The myriad filter seems to perform better than the Kalman filter, giving a better tracked output and requiring no 'training' time to lock onto the target. The errors in the DOA estimates seem have an impulsive rather than Gaussian distribution. The myriad filter assumes an impulsive distribution where as the Kalman filter assumes Gaussian noise, therefore the myriad filter should perform better. Also the Kalman filter assumes constant velocity; where as myriad filter makes no such assumptions.

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