# CREATING AN INCOHERENT SYNTHETIC APERTURE USING AN AUTONOMOUS PROFILING VEHICLE

Parijat D. Deshpande, Venugopalan Pallayil, Boon Siong Wee, Paul J. Seekings, and John R. Potter

Acoustic Research Laboratory, Tropical Marine Science Institute, National University of Singapore,
12 A Kent Ridge Road, Singapore 119223

## Abstract

Acoustic synthetic apertures are usually generated by coherent summing of signals, correcting for phase shifts due to the lapse in time as a receiver array moves to create the aperture. This approach suffers from phase estimation errors arising from both positioning errors of the moving receivers and from phase instabilities in the signal. An incoherent synthetic aperture can be created if compact broadband signals are used, avoiding phase error problems. Furthermore, since no overlapping sensors are required for phase estimation, a synthetic aperture can in principle be created from a single moving receiver. This paper investigates the feasibility and expected performance of an incoherent synthetic aperture constructed by moving a single acoustic receiver in the vertical plane. The application discussed in this paper is to evaluate the focal region of an Acoustic Time Reversal Mirror (TRM) where the receiver platform is an Autonomous-Profiling Vehicle (APV). The APV is a modified commercial product from Ocean Sensors in San Diego, USA, and carries an acoustic data acquisition payload designed by the Acoustic Research Laboratory. The APV has the ability to profile in the vertical plane, guided by a taut vertical mooring line, or to zigzag in a series of progressively displaced vertical profiles as it drifts freely with currents. The APV also monitors conductivity, temperature and depth, so that the sound speed profile and the depth of the receiver at each pulse reception can be reconstructed. Numerical propagation models are used to simulate the performance of such an incoherent synthetic aperture array during shallow water TRM experiment to validate the overall performance prior to conducting sea-trials. Both Fast Field (SPARC) and Normal Mode (Kraken C) models are applied. The temporal-spatial ambiguity problem is considered with respect to the time it takes to form the aperture compared to the coherence time of the TRM focussing, limited by the coherence time of the shallow-water waveguide. We also present some CTD and acoustic data taken by the modified APV.

## Introduction

Acoustic synthetic apertures are used in many underwater applications such as seabed imaging to form high-resolution images [1,2]. However their use in Time Reversal Mirror Experiment (TRM) is not widely studied. Conventional synthetic aperture technique often employs coherent summing of the signals while correcting for phase instabilities due to aperture movement to achieve the required tasks. Such a system suffers from the position estimation errors and phase instabilities due to the motion of the aperture. An incoherent synthetic aperture can solve these problems to some extent by the use of a broadband signal. An incoherent approach has the following additional advantages [3,4]:

- Absence of grating lobes
- Flexible array configuration
- Shorter processing time

An incoherent synthetic aperture, in principle, can be created using a single moving receiver and does not require overlapping sensors for gathering phase information. This paper addresses the use of an incoherent synthetic aperture for estimating the focus of a Time Reversal Mirror (TRM) experiment. In a TRM application a multi-element vertical receiver array, which is very bulky and expensive, is used as a receiver for coherent processing and to get the focus of acoustic energy [5]. Here we describe the use of an Autonomous Profiling Vehicle (APV) for such an application.

APV is an ocean profiling system manufactured by Ocean Sensors Ltd., USA [6,7]. The system can traverse up and down, over a tethered line, collecting environmental data such as temperature, conductivity and depth and transmit them over a Radio Frequency (RF) link to a user receiver system. A photograph of the APV is shown in figure 1. Acoustic Research Laboratory (ARL) has incorporated an acoustic measurement payload comprising a hydrophone and a data acquisition system into a commercial APV for use as an incoherent synthetic aperture in a TRM experiment.

The first section of the paper describes the theoretical performance of the incoherent synthetic aperture in a TRM experimental scenario. This is followed by a description of the data acquisition payload designed and developed in-house for acoustic data collection. Finally some environmental and acoustic data obtained from the measurements using APV are presented.

## Incoherent Synthetic Aperture – Numerical Modelling

The theoretical validation of the above problem has been carried out by numerical modelling of an Acoustic TRM experiment in a shallow underwater scenario with a known stationary noise source using SPARC (SACLANTCEN Pulse Acoustic Research Model) Fast Field algorithm [8]. The TRM experimental scenario is shown in figure 2. A probe source (omni directional source) transmits an acoustic pulse and an array of transducers at a distant location receives the information, time reverses it and re-transmits it back to the probe source after the source has completely transmitted the signal. A vertical receiver array near the probe source collects all the retransmitted energy and estimates its focus. In figure (2), a conventional TRM vertical receiver array at the probe source has been replaced by an APV traversing up and down the water column, over a tethered line. The APV is assumed to be co-linear with the probe source for simulation purposes.

The APV collects the retransmitted data from the array of sensors at regular intervals as it traverses along the line. A second set of data is collected while the APV goes up the line to the surface. As an APV cannot take data continuously it needs to be decided what sample size would give a reasonable energy estimate. To estimate the sample size a TRM experiment with 9-element vertical receiver array was assumed. The re-transmitting array or the source receiver array was assumed to be located about 1 km away from the probe source. A frequency limited Gaussian pulse train (frequency of 1 kHz) was sent out from the probe source. The pulse length of 4ms and their separation of 25ms were chosen to ensure that the received signal did not contain the multi-path reflections of the preceding pulse Fig:0.

The receive-source array receives all the direct and multi-path reflections as depicted in figure 6.

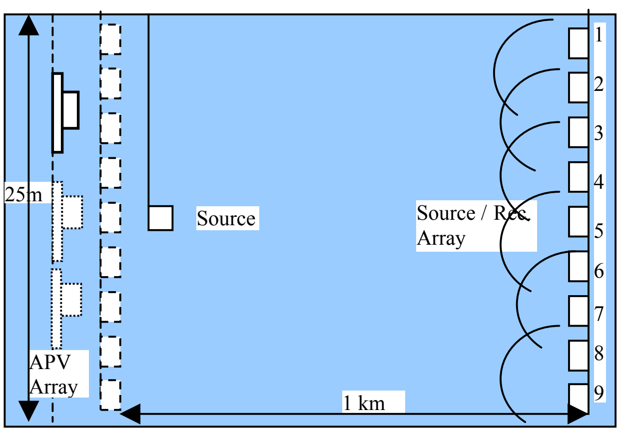


Fig 2. TRM Experimental scenario

The signals are then time reversed and re-transmitted by the source receiver array. As long as the medium parameters do not fluctuate, the signal should focus back at the probe source and this focus can be measured by a vertically translating APV.

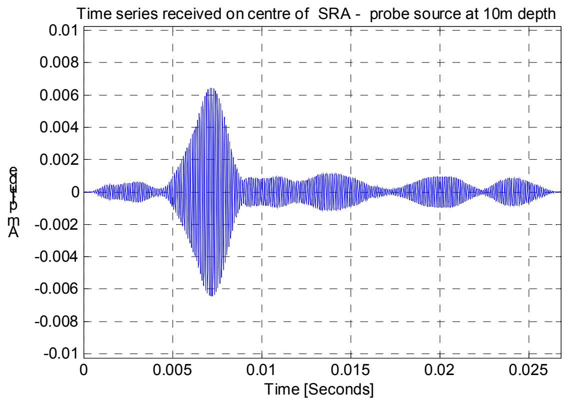


Fig.0 Single Pulse received at Rec. Source Array


Fig. 1 Photograph of the APV

Discrete data sets at nine APV locations were taken to simulate a possible incoherent APV array at the receiver end. The energy output at any location will be a function of the number of samples taken at that point. So before the actual experiment the number of samples that needs to be taken has to be fixed.

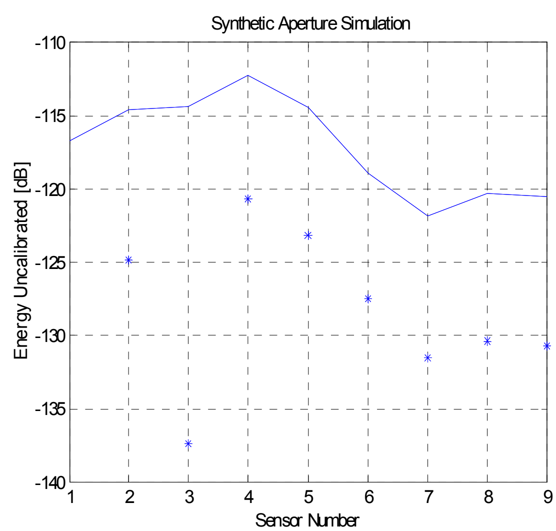


Fig. 3 Continuous vs. APV Array with sample size 6000

Figures 3 to 5 illustrate the energy estimates obtained for the different sample sizes. For example, figure 3 shows the energy estimate for an APV, which took approximately 6000 samples at each location. In figures 4 and 5 the sample sizes are 1100 and 100 respectively. The graphs also show the energy estimate for a continuously sampled system as indicated by the solid line. From a comparison of the two plots it is clear that to get a reasonably good estimate of the energy distribution a sample size of 6000 should be used for this experiment.

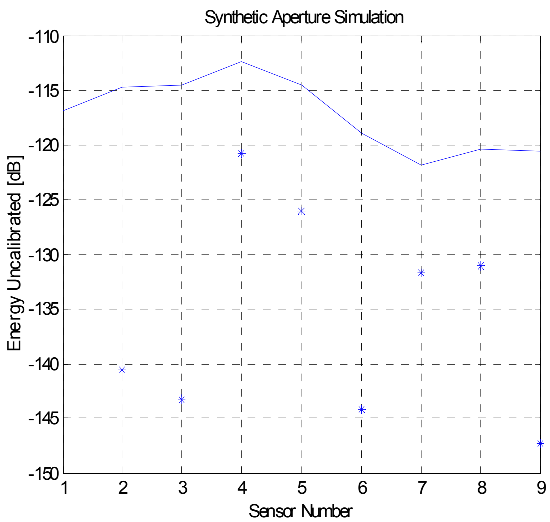


Fig.4 Continuous vs. APV Array with sample size 1100

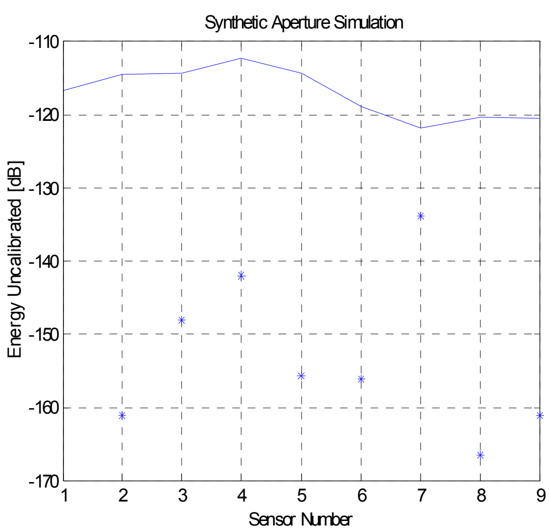


Fig. 5. Continuous vs. APV Array with sample size 100

The difference between solid line and the points in figures 3, 4, 5 is due to the fact that APV array records at discrete number of locations resulting in recording fewer samples as compared to continuous recording by a fixed line array.

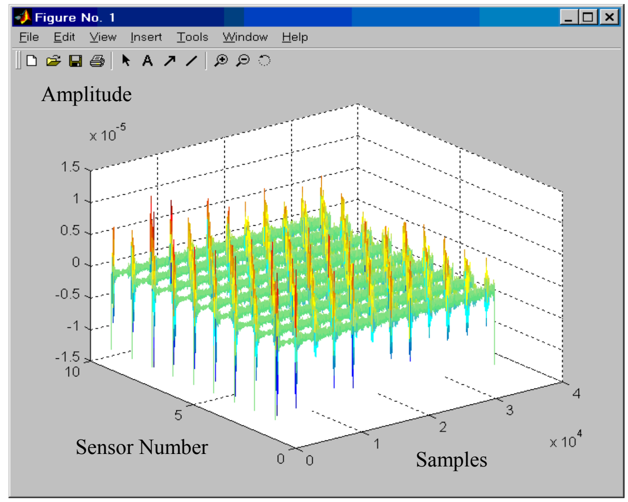


Figure 6. The receivers at the other end receive a multi path reflection of all the pulse trains sent by the source.

Once the sample size was fixed the next step was to see how well a vertically translating APV could measure the signal energy focus. The APV moves continuously at its terminal velocity of approx. 0.33m/s after the initial acceleration phase and therefore it will only be able to collect a much smaller data set at a given location. For a typical 25 m deep scenario, expected around local waters, the APV traverses the distance in 100 sec. The APV collected data at 9 locations both during its upward and downward movements. The results are discussed below. The results are also compared with those obtained using a continuous array of nine equally spaced sensors.

Figure 7 shows a plot of energy level received at different sensor positions of the continuous array. As is clear from the figure, the maximum energy is recorded at sensor number 4, which occupied the same location as that of the probe source. This clearly demonstrated the TRM functionality.

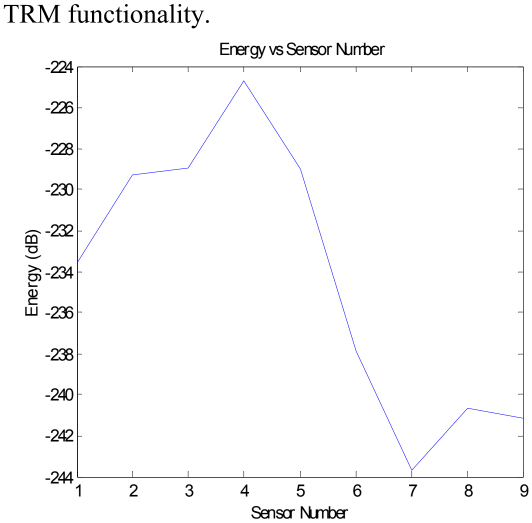


Figure 7. Plot of energy levels as received at all sensors

The vertical receiver array was now replaced by the APV and figure 8 shows a plot of the signal energy received at the nine different locations. Again the APV location 4 has the highest energy. The APV was taking 6000 samples at each of its location. The results showed that the APV can in fact replace a costly and bulky vertical receiver array in a TRM experiment. The validation of theory using experiments is in progress and will be available during the Conference presentation.

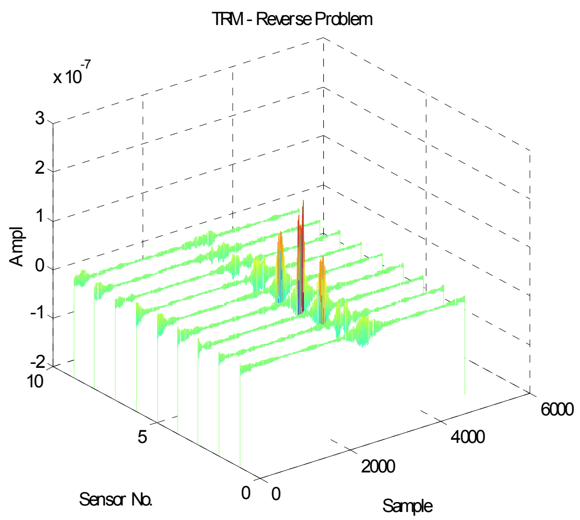


Figure 8. Plot of 6000 samples received at each APV location

## Data acquisition payload for APV

To validate the above theoretical observations an experiment was conducted. To conduct the experiment a data acquisition payload was required to be designed, as the commercial APV does not incorporate one. A PC104Plus based data acquisition system was developed and tested for use in an APV. A block diagram of the developed system is shown in figure 9 and a photograph in figure 10. The data acquisition card used was an 8-channel differential input card from Real Time Devices, USA. An RS232 interface was built to interface the data acquisition system with an external PC. The PC-anywhere® remote control software was used to talk to the PC-104 over the RS-232 link. The PC was also interfaced to the APV buoyancy control unit and environmental data acquisition system through the PC104 processor and another RS-232 link.

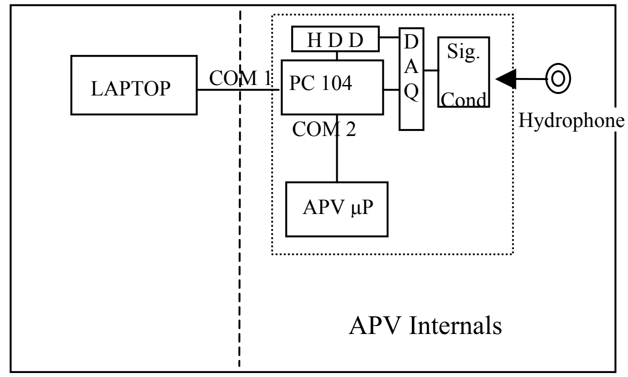


Fig. 9 Block diagram showing interconnections between different electronics blocks

The hydrophone HTI-91 manufactured by Hi-Tech® Inc., USA was used for receiving the acoustic signals. Provision has been made to mount two hydrophones units on the APV although currently a single hydrophone is being used.

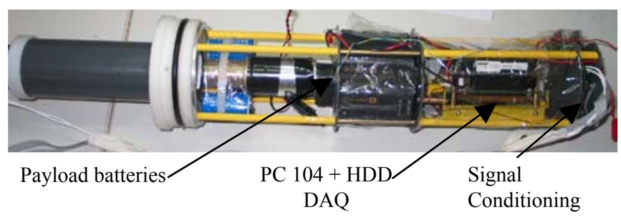


Fig. 10. Modified APV payload with the data acquisition system

The system has been tested out in an acoustic tank-using signal source (ITC-1042) and was found to be working satisfactorily. A Matlab program was used to read the data and to analyse it. Currently field experiments are in progress to verify the utility of the system as an incoherent synthetic aperture. The results from these experiments will be presented during the oral presentation after due clearances.

The APV has been deployed in many areas of Singapore waters for collecting environmental data. A typical plot obtained is shown in figure 11. This data has been validated using a hand held CTD SD204 as reference. [9]

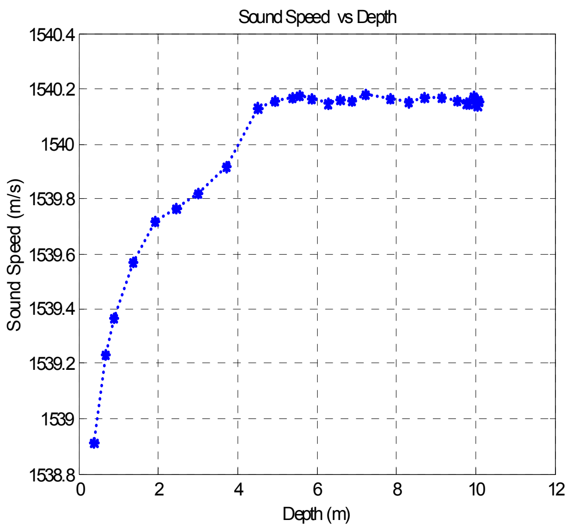


Fig.11 Sound speed vs. depth

## Conclusion

The idea of using a vertically translating APV as an incoherent synthetic aperture has been explored. It has been shown through numerical modelling that the APV can replace a vertical receiver array in a TRM experiment and give reasonably accurate results.

A data acquisition payload has been designed and tested out to verify the idea through experiments. Some environmental data collected using APV has been presented and verified with data from a hand held CTD. A field trial will be conducted shortly to verify the concepts experimentally.

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