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SONOBUOY DISPLAY INTEGRATION

Jimmy Wang, Simon Lourey and Richard Ellem

Maritime Operations Division
Defence Science and Technology Organisation
PO Box 1500, EDINBURGH, SA 5111, Australia
Email: Jimmy.Wang@defence.gov.au

Abstract

Sonar data integration can be performed at various levels throughout the sonar processing chain with varying complexity, cost and benefit. In this paper, we present research results on the integration of sonar data at the display level, which may potentially enhance the submarine detection capability for Anti-submarine Warfare (ASW) sonar systems. The primary aim of sonar display integration is to enhance the capability of a network of sonar systems in the detection of weak targets that may otherwise not be detected by an individual sonar system. We show that this can be achieved through the display integration of sonobuoy tactical displays with sea trial data. One added advantage of this technique is that once a weak target is detected it is also localised.

1. INTRODUCTION

A *sonobuoy* is an expendable sonar system that is usually deployed from aircraft or ships for ASW operations or underwater acoustic research. Detection, classification, localisation and tracking are the four fundamental tasks for a sonar operator. Of these, the initial detection of a potential contact, by a single passive or active sonar system, is the first and usually most difficult. This is due to the complex modes of propagation of underwater sound, the presence of ambient noise sources and the reduction of radiated noise from modern conventional submarines. Consequently, the integration of data from multiple sensor systems on a single or multiple geographically separated platforms is widely regarded as a promising strategy for combating this problem. As discussed in [1], sonar data integration can be performed at various levels including raw data level, detection level, information level and display level. Each type of integration is beneficial to a sonar operator in performing one or more of the four fundamental tasks to a certain extent. For example, integrating data from multiple sensors at spatially separate locations vastly improves the accuracy of target localisation and target motion analysis. Contact bearing ambiguity (unable to determine whether the contact is located on the left or right hand side of the array) associated with a linear array such as a towed array or seabed array may be resolved with the help of an additional directional sensor such as a sonobuoy.

In this paper, we present a technique of integrating a number of sonar tactical displays, which enhances the capability of the detection of a weak target that may not be detected by any individual sonar system present. An added advantage of this technique is that target localisation is resolved as soon as it is detected. A sea trial was conducted with sonobuoys as receivers to obtain real data to validate the technique.

This paper consists of four sections. Section 2 provides the details of a sea trial specifically conducted in support of this study. In Section 3, the correlation processing for signal time-of-arrival analysis and the localisation of sonobuoys are presented. Section 4 presents the technique of display integration and the result of its application to sea trial data. Section 5 summarises research presented in this paper and outlines the potential applications of this technique and possible future research in this area.

2. THE SEA TRIAL

A sea trial was conducted in Gulf St. Vincent off South Australia. Two types of sonobuoys, Type B and Type D, were used as acoustic receivers. A Type B sonobuoy has relatively accurate contact bearing resolution, but is subject to drifting by ocean current. A Type D sonobuoy has poorer contact bearing resolution, but has fixed location since it can be anchored in place. The objective of this trial was to collect sonobuoy data to support research into sonar display integration.

A maritime patrol aircraft deployed eight Type B sonobuoys and then the trial vessel deployed five Type D sonobuoys in the same area. The GPS reading of the actual positions of the Type D sonobuoys was recorded. An acoustic transmitter with GPS was employed as a source at a number of locations. All pings by the transmitter were *linear frequency-modulated* (LFM) sweeps from 1.1 kHz to 1.8 kHz in 0.5 seconds. The source power of the pings varied with some high source power pings to be utilised in the localisation of Type B sonobuoys as described in the next section. Figure 1 shows the location of the five Type D sonobuoys and the estimated location of two Type B sonobuoys.

3. SONOBUOY LOCALISATION

Knowledge of sonobuoy location and reasonably accurate contact bearing resolution are the two critical requirements for the successful execution of the display integration that we propose. Sonobuoys, once deployed, are subject to drifting which has been a major limiting factor for accomplishing the full potential of sonobuoys in providing more accurate tactical information such as potential target location, etc. If sonobuoy locations are known to some accuracy, we may localise a target better and improve the detectablity of a weak target utilising data integration techniques. A Type B sonobuoy can give relatively accurate target bearing information whilst a Type D can only supply a crude estimate. In the sea trial, all Type D sonobuoys were anchored at the sea floor. A GPS reading of these Type D sonobuoys provided us accurate location information. Figure 2 shows how we localised the Type B sonobuoys.

For each ping, we can estimate the time that it arrived at each of the Type D and Type B sonobuoys. This is achieved through the application of correlation processing on the known LFM transmission and the beamformed time series of the Type D and Type B sonobuoys. Assume t_D and t_B are the time instants that the transmitted signal arrived at the Type D and Type B sonobuoy respectively. Then we know that Type B sonobuoy *B* must reside on the circle with radius $R_D + c(t_B - t_D)$ where R_D was the range between the Type D sonobuoy *D* and the transmitter and c is the sound speed. The location of the Type B sonobuoy can then be derived with the bearing information of the transmitter given by the Type B sonobuoy. The accuracy of this localisation depends upon the accuracy of the estimates of the arrival time at the Type D and Type B sonobuoy and the bearing resolution of the Type B sonobuoy.

Now let $x(n), 0 \le n \le N-1$ be the receiver time series and $y(n), 0 \le n \le M-1$ be the transmitted LFM pulse with $M \le N$. The *correlation coefficients* of $x(n)$ and $y(n)$ are defined as

$$r_{xy}(l) = \sum_{n=l}^{M-1+l} x(n)y(n-l) \quad 0 \le l \le N-M,$$

and

$$r_{xy}(l) = \sum_{n=l}^{N-1} x(n)y(n-l) \quad N-M+1 \le l \le N-1.$$

The peak of the function $r_{xy}(l)$ corresponds to the arrival time of the transmitted signal at the receiver. In Figure 3, the top plot shows the beam number 56 of beamformed time series of a Type B sonobuoy and the bottom plot shows the correlation coefficients with the transmission being a 0.5 second LFM from 1.1 to 1.8 kHz. A sequence of 24 sharp spikes is clearly visible in the correlation coefficients plot. These represent the arrival time of the 24 high source level pings transmitted during the trial. Figure 4 provides close-up view of the section that contains the first ping.

We estimate the time of arrival at both Type D and Type B sonobuoys and then determine the locations of two Type B sonobuoys from the known transmission location, the bearing information given by the Type B sonobuoys and the known location of a Type D sonobuoy. We can now start the integration of the tactical displays of these two Type B sonobuoys.

4. DISPLAY INTEGRATION

The increase of the processing power and available communication bandwidth has allowed some tremendous progress in both theoretical developments and practical applications of data integration technology. Sonar data integration is a critical technology area for *network enabled warfare* and has been identified as a key component in the provision of an integrated undersea tactical picture. Data integration can be carried out at various levels of the sonar signal and information processing chain. In this paper, we focus our effort on the integration of tactical displays.

Within a surveillance area, a number of sonar systems may be deployed to provide a more complete coverage. Each of them has its own tactical display in the form of bearing-range display. Some of the displays may cover common areas, which presents us with an opportunity to exploit information supplied by more than one sonar systems for such common areas. For simplicity, we focus our discussion on how to integrate tactical displays of two sonobuoys. The principle remains the same for more than two sonar systems of any type. Figure 5 shows the tactical displays of two sonobuoys *B1* and *B2*. It is possible to integrate the displays over the entire common area by summing up the corresponding power values for each cell. For easier discussion and graphical illustration, we only consider a circular region within the common area centred at *B2*.

In Figure 6, *P* represents a cell in the common area. In order to sum up the power value of *P* in the tactical display of *B2* to that of *B1*, we need to find the range and bearing of *P* in relation to *B1*. The simplest way to achieve this is through the following series of coordinate transformations. The bearing and range of *P* with respect to *B2* represent the polar coordinates in the local polar coordinate system of *B2*. They can be converted into the local Cartesian coordinates of *B2* which are then transformed into local Cartesian coordinates of *B1*. Finally, they are converted into local polar coordinates of *B1*. These represent the bearing and range of *P* with respect to *B1*.We can then sum up the power values for this cell. An integrated display can be created by repeating this process for each of the cells in the common circular region.

Figure 7 shows the tactical displays of *B1*, *B2* and the integrated display with the power values in all three displays being normalised to between 0 and 1.The same displays in rectangular format are shown in Figure 8 with the horizontal axis representing bearing angle and the vertical axis representing range. The true north direction corresponds to a bearing value 0 and the bearing value increases in the clockwise direction. The rectangular displays suit this particular display integration technique better due to the fact that, in a circular display, a beam becomes wider in physical space as the range increases, which distorts the size of the target. We can see that the weak contacts in beam 56 with range beyond the clearly visible strong contacts stands out in the integrated display much more clearly than in the two individual sonar displays. The reason for this is that the sum of the two power values tends to the sum of mean values of the two random variables representing the power values for a cell. Therefore, the fluctuation of the background is suppressed. This is somewhat similar to the effect of beamforming where signals are reinforced when they are summed in phase over a number of elements. The summation of signals out of phase tends to decrease the amplitudes, hence the signal power.

The second plot in Figure 9 shows the power values of all cells with a fixed range in the tactical display of *B2*. The first plot shows the power values of those cells in the tactical display of *B1*, whilst the third plot shows the summed power values of these cells, namely the power values of the same cells in the integrated display. Clearly, we can see that the weak target in beam number 56 is easily detectable as the background is flatter than that in the individual sonar displays. The *Law of Large Numbers* states that the sum of a number of random variables tends to the sum of the expected values. Therefore, for this case, the sum of two random variables representing the power values for these two sonobuoys tends to the sum of the individual expected values. The gain in terms of signal to noise ratio is about 1dB which enables us more easily to detect the weak target. Furthermore, this display integration technique has an added advantage in that once a target is detected, it is also localised because we can obtain the bearing and range of this target from the integrated display. Also, the gain is expected to increase as the increase of the number of sonobuoys used for the display integration provided that the accurate enough locations of the sonobuoy are known.

The sonobuoy location accuracy requirement depends on the size that the target appears on the display, the cell size and the power distribution of the target in the tactical displays. Some sonobuoy location error can be tolerated as we may still be able to obtain a large enough gain for the purpose of the target detection although we may not be able to achieve the maximum gain that is achievable with accurate sensor location information.

5. SUMMARY

In this paper, we discuss a tactical display integration technique and demonstrate the effectiveness of this technique with sea trial sonobuoy data. It is shown that sonar display integration may potentially provide the detection of a weak target that may otherwise not be detected by an individual system in the common coverage area of two or more sonar systems. This has the potential to be particularly significant for operations in acoustically complex shallow water environments where the detection of a weak target is even more challenging. Another advantage of this technique is that it also localises the target once it is detected.

REFERENCES

[1] J. Wang, M. McIntyre, S. Taylor, J. Riley and R. Ellem, Integration of surface combatant ASW sensors, *Proceedings of the TTCP Maritime Systems Group, Technical Panel 10, October, 2000, Halifax, Canada.*

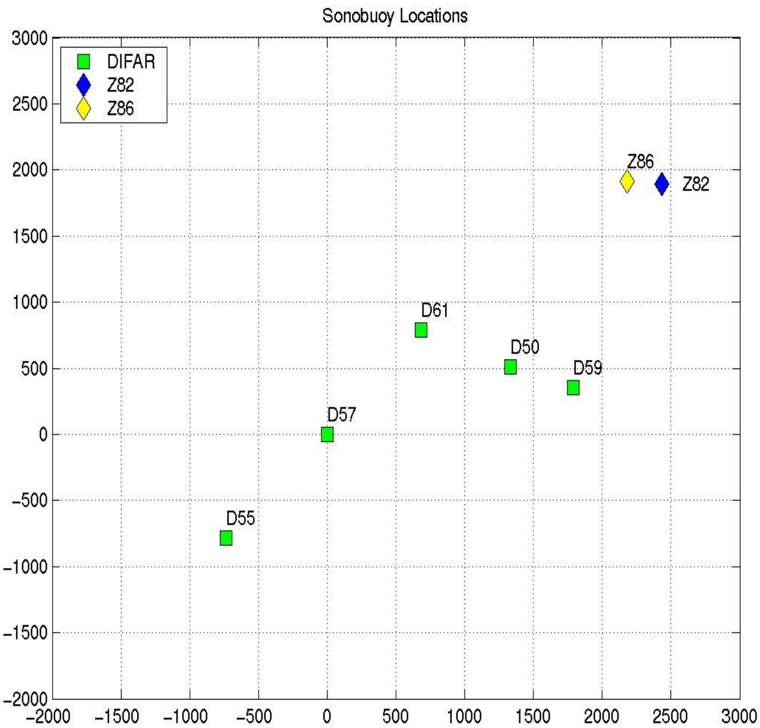

Figure 1. Sonobuoy Locations. D50, D55, D57, D59 and D61 are Type D sonobuoys and Z82 and Z86 are Type B sonobuoys.

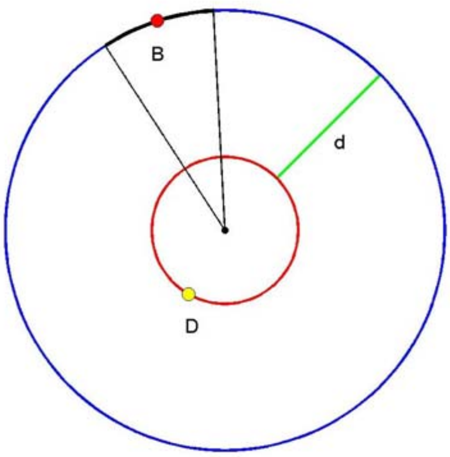

Figure 2. Type B sonobuoy localisation. Transmitter is located in the centre. B and D represent the locations of a Type B and a Type D sonobuoy respectively.

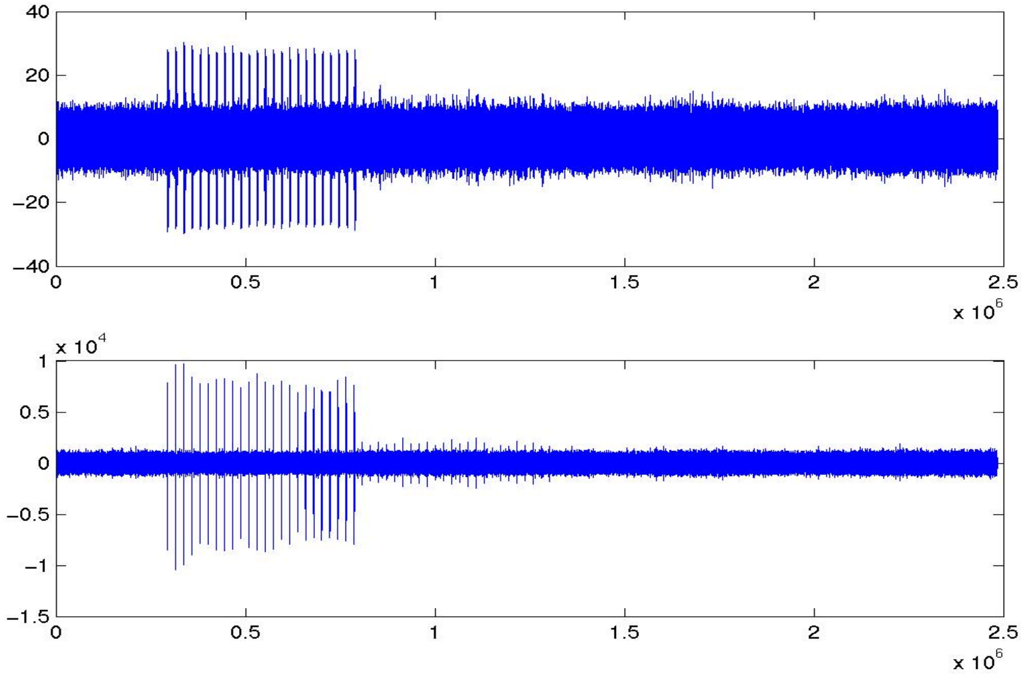

Figure 3. Beamformed time series (top) and the correlation coefficients (bottom). The 24 high powered pings are clearly visible.

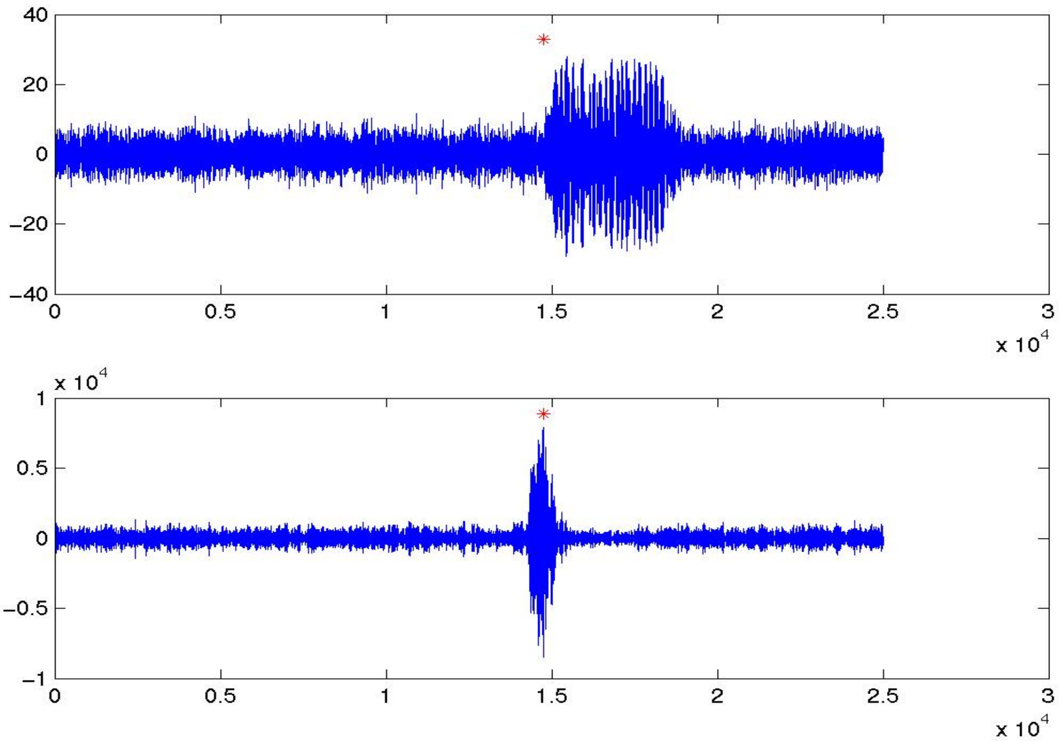

Figure 4. Close up view of the section that contains the first ping.

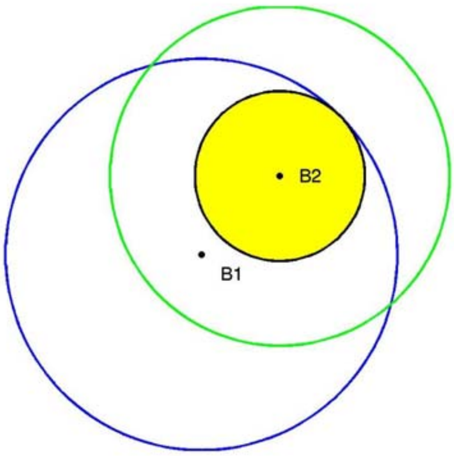

Figure 5. Area for display integration

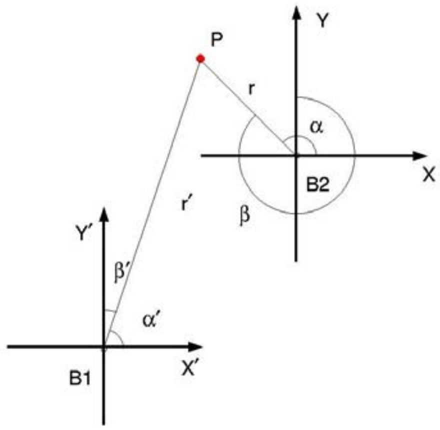

Figure 6. Cell to cell association

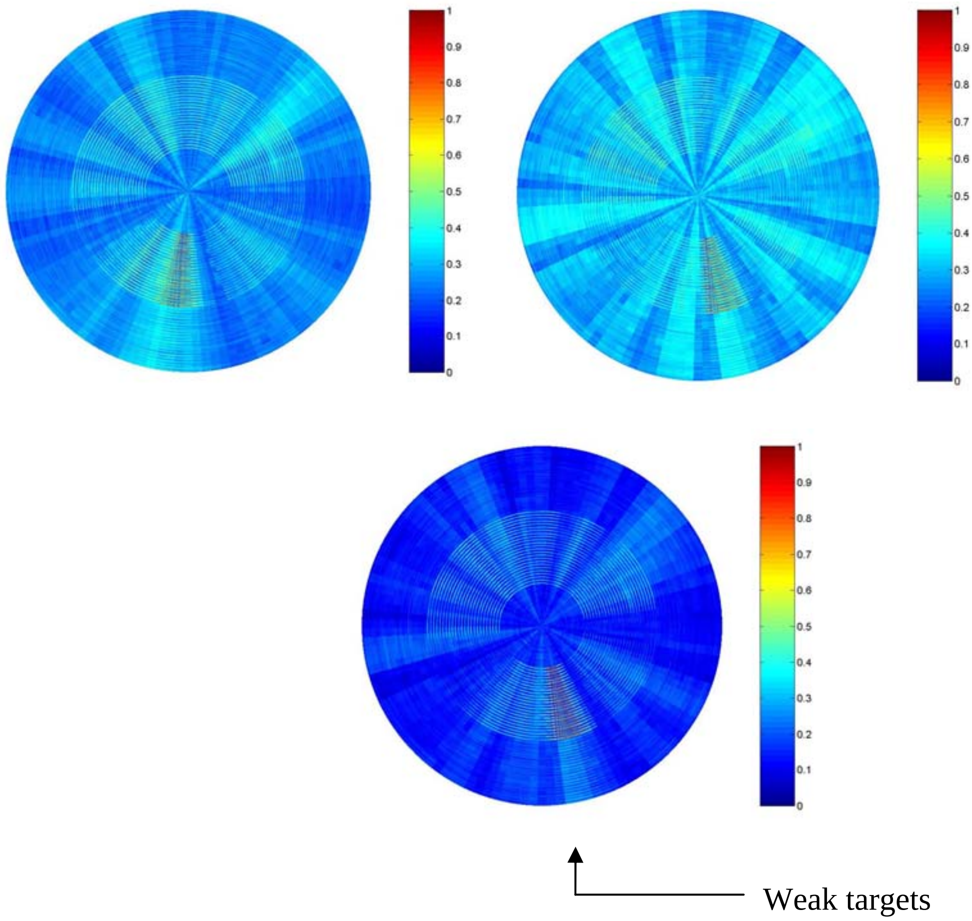

Figure 7. Two individual sonobuoy displays (top) and the integrated display (bottom). The weak targets are more easily detectable in the integrated display.

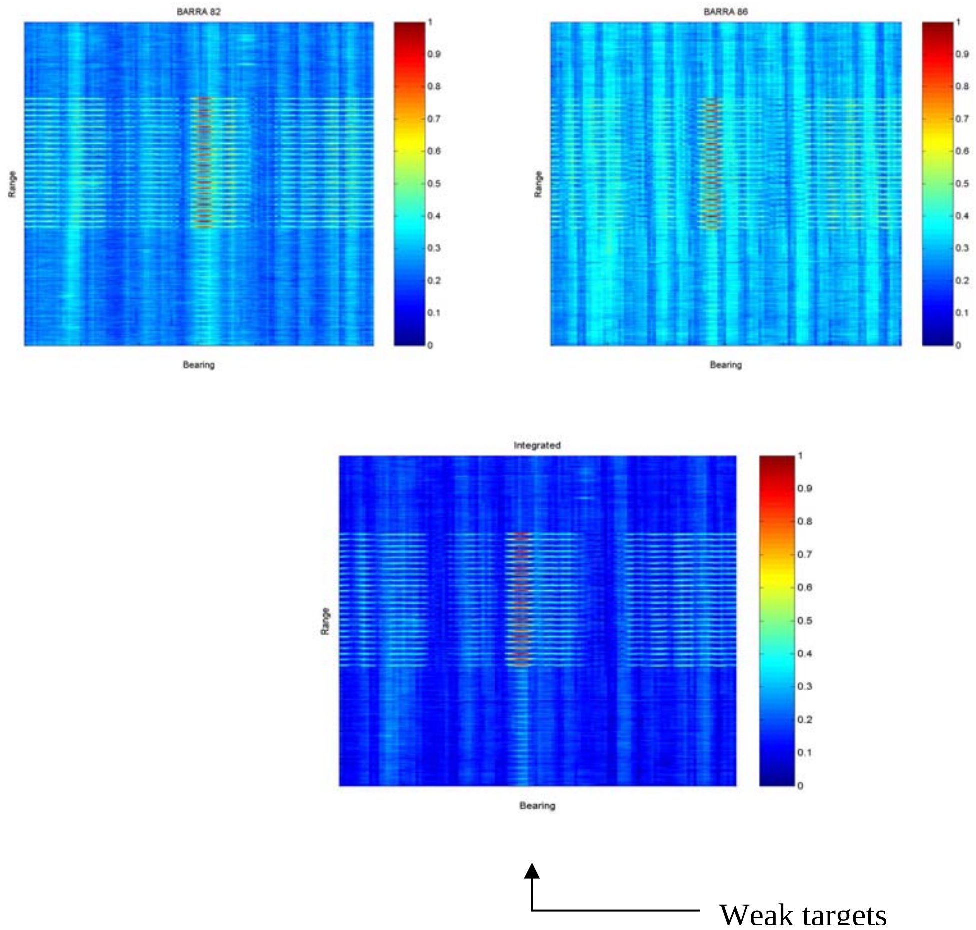

Figure 8. Two individual sonobuoy displays (top) and integrated display (bottom) in rectangular format. The weak targets are more easily detectable in the integrated display.

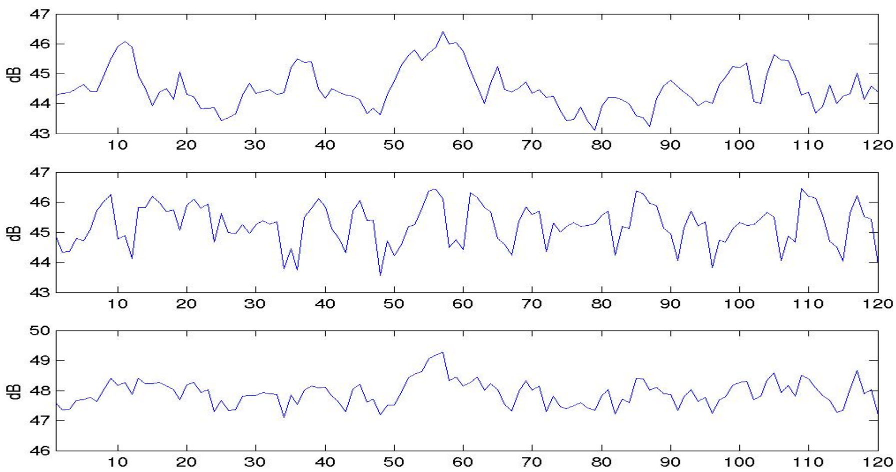

Figure 9. Illustration of the effect of display integration over cells with a fixed range. The top plot shows the power values of the cells with a fixed range in the tactical display of B1. The middle plot shows those of B2. The bottom plot shows the summed power values of the corresponding cells of B1 and B2, namely the power values of the same cells in the integrated display. The weak target in beam number 56 is more easily detectable as the background is flatter in the bottom plot than in the top and middle plots.