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DETECTION ENHANCEMENT USING COLOUR FOR SONAR DISPLAYS

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ABSTRACT

This paper describes an investigation of the effect of the inclusion of colour coded signal information in frequency-time-intensity (lofargram) sonar displays on the detection threshold of human observers. An average measured 'colour gain' for human observers gave a systemic improvement in performance which partially negated typical human factors losses associated with making detection decisions from sonar displays. The effect of good and poor contrast between colour hues was also studied for its effect on signal detectability and the quality of bearing information on the display. It was found that the relative brightness of the display cells was the dominating factor in signal detection on lofargrams, rather than the specific choice of colour hues, and that each display must have its choice of colour hues individually tuned for maximum benefit.

INTRODUCTION

The availability of high resolution colour video monitors for use in sonar systems has led to interest in the use of colour to enhance the performance of human observers. In antisubmarine warfare (ASW) operations there are typically four quantities of interest to the observer. For a passive sonar system the parameters are frequency, bearing, received signal to noise ratio (SNR) and time history, while for an active sonar the desired parameters are Doppler shift, bearing, SNR and time history (equivalent to range) (Ref. 1). A single monochrome display is typically limited to showing only the SNR and two other parameters, thus requiring the observer to use multiple displays to cover all the necessary combinations of parameters.

Buratti , Rio and Witlin (Ref. 2) have used colour coding within a standard active sonar display to provide additional Doppler information where a monochrome display would show only the range, bearing and SNR over a time history of sonar pings. The average measured improvement in target detection performance by the human observers was 1.5 dB.

In the work reported here the aim was to obtain a similar enhancement of the detection performance of human observers using passive sonar displays. In passive ASW operations the most commonly used sonar search display is a frequency-time-intensity ('lofargram') display. This effectively uses three dimensions of information on a two-dimensional monochrome display. Thus one logical use of colour coding would be to include information based on the fourth desired quantity, that of signal bearing.

MODELLING DETECTION THRESHOLD (DT)

The theoretical detection threshold (DT) for this experiment was modelled as:

$$DT = 11.4 - 10\log_{10}(ndl) \text{ dB}, \quad (1)$$

where *ndl* is the number of independent rows of data on the display being used by the observer to make the detection decision. In this experiment *ndl* = 24. Equation 1 is the theoretical estimate of DT based on the use of Gaussian statistics for the noise with probability of detection (PD) = 0.5 and probability of false alarm (PFA) = 10^{-4}. These values of PD and PFA represent typical operational values.

Equation (1) also assumes the sonar system contains an 'ideal' observer. However, there are some necessary correction terms to account for display losses and the use of human observers in place of the theoretical 'ideal' observer. For human observers there is a consistent difference between the theoretical and observed detection performance of the visual integration gain (effectively the time history) component of the detection threshold: this was measured by Dawe and Grigorakis (Refs. 3, 4) and found to be 3.5 ± 0.5 dB for *ndl* = 24. Quantising the displayed results into discrete steps of colour saturation gives a quantisation loss (Ref. 5), measured for this system as being 0.6 ± 0.3 dB for *ndl* = 24. As the human observers may have a performance change due to the presence of colour information, this must be accounted for as a 'colour gain' (CG). Collecting all of these terms together gives the modelled detection threshold for human observers as being:

$$DT = 1.7 - CG \text{ (dB)}. \quad (2)$$

With a monochrome lofargram the observer is only examining the display for 'lines' of significantly higher luminance relative to the average background level (i.e. the intensity component of the frequency-time-intensity display). With the multicolour, or 'polychrome', display the observer is also looking for a relative contrast in hue between suspected signal lines and the average scatter of hues in the background. This is effectively an extra degree of freedom and so, according to Buratti, Rio and Witlin (Ref. 2) it should improve the average detection performance of the human observers by 1.5 dB. For an 'ideal' observer there should not be any significant colour gain: this is because the ideal observer makes the detection decision based on a detailed knowledge of the numerical values in each display cell. The human observer is instead using pattern recognition techniques to make detections, and this will still be true for colour coded display cells. Further work may enable the ideal observer to also make use of the colour-coded information to assist with detection decisions.

THE EXPERIMENT

To simulate a simple lofargram type of display using an IBM-compatible personal computer, a program called LOFARSON was used which generated either a preset or random number of constant strength signals in a background of white (Gaussian) noise for a given number of display rows. Each of the eight observers then used a cursor to indicate what they considered to be a signal rather than noise. LOFARSON generated a sequence of 10 of these displays, at the end of which the detection threshold was calculated based on each observer's detection and false alarm statistics at each SNR. An example (rendered in black and white) of LOFARSON in operation is shown here as figure 1. More details of LOFARSON can be found in Galbreath (Ref. 6).

Once a signal was generated it had a fixed frequency with a minimum spacing between the signals corresponding to twice the allowed marking tolerance. The background noise was generated as a set of uniformly distributed pseudo-random numbers which were transformed to have a Gaussian distribution, with zero mean and unity standard deviation for convenience of analysis. Each pixel of the lofargram display corresponded to either a noise sample or a sample of noise with a signal added.

The samples of noise and signal plus noise were linearly quantised to four levels and the result was used to define the display cell intensity for the monochrome lofargram displays, or the saturation of the hue for each of 16 bearing sectors for the polychrome lofargram displays. The selection of colours denoting sectors is shown Table 1 and was based on a red-yellow-green-blue colour wheel (Ref. 7). The actual saturation distribution was a function of the visual display unit which was used to display LOFARSON.

The choice of 16 equal bearing sectors was completely arbitrary and in this case was selected to match the points of the compass. Of course, specific sonar applications would benefit from matching the number of hues to the number of beams used by the system. With 16 colour hues making the display relatively complicated for the observers to study, using a large number of saturation levels within each hue would provide no significant benefit as many of the intermediate levels would tend to appear similar to those of adjacent sectors due to chromatic induction. See Widdel and Post (Ref. 7) for an extensive overview of perceptual artefacts associated with the use of colour in electronic displays.

LOFARSON allowed the signal levels for the different tests within a set to be automatically adjusted to obtain, on average, a 50% probability of detection (PD), via a process of iteration based on past observer performance. For each test within a set the program computed PD: if PD < 50% for that test then the program increased the SNR on the next test. Conversely, if the measured PD > 50% for a particular test, the program decreased the SNR on the next test. In this way the program used the observer's measurements over a set of 10 tests to iterate about the PD = 50% level. Examples of this adjustment within the test set can be seen in the summary information in the lower half of figure 1.

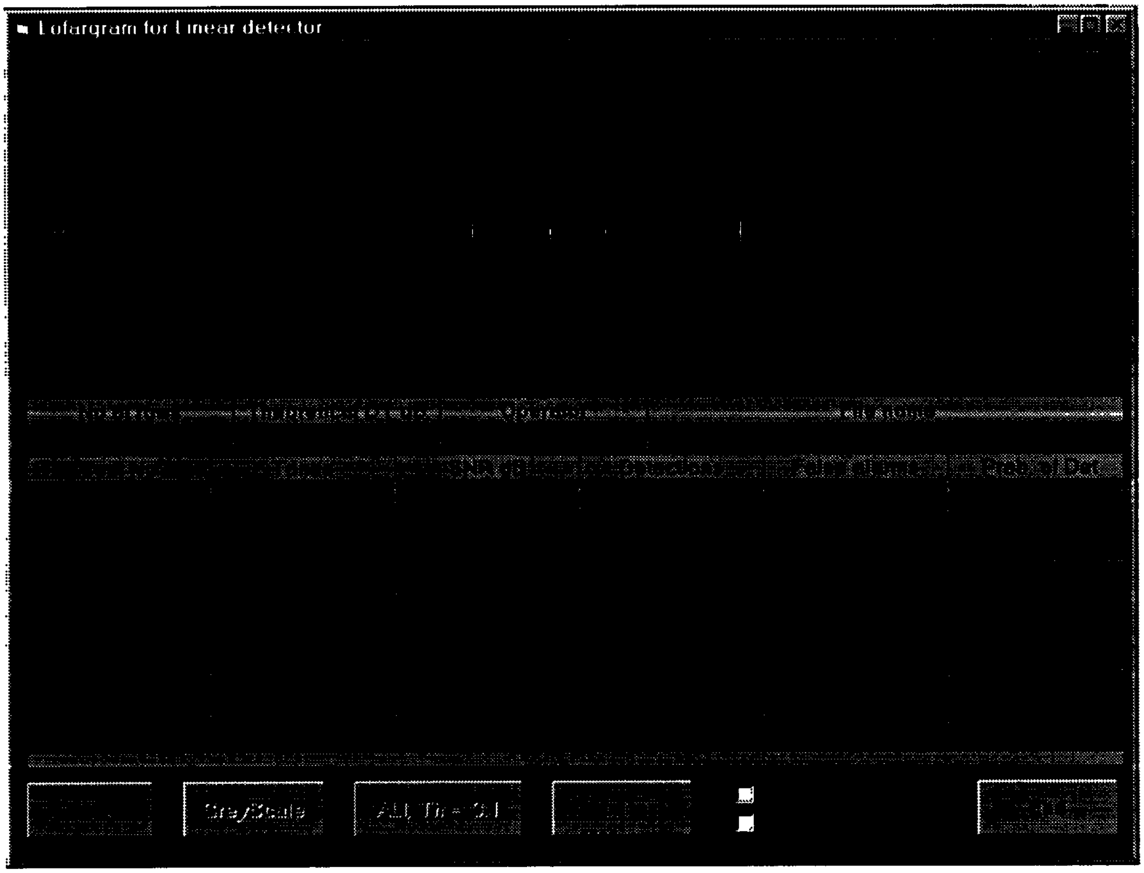

Figure 1. An example of the type of screen display generated by LOFARSON. The upper portion of the screen shows the general form of a lofargram: frequency is along the horizontal axis, time is on the vertical axis and the pixel intensity is related to the input SNR. Marks just below the lofargram indicate correct or false detections. The lower portion of the screen shows items related to the previous tests.

Bearing Sector	Hue	Bearing Sector	Hue
1	'Pure' Red	9	'Pure' Green
2	Red-Orange	10	Green
3	Orange	11	Green
4	Orange-Yellow	12	Cyan
5	'Pure' Yellow	13	Light Blue
6	Yellow	14	Dark Blue
7	Yellow-Green	15	Purple
8	Green	16	Pink

Table 1. Selection of colour hues for the bearing sectors in the polychrome displays: they are spaced relatively evenly around the colour wheel. The inclusion of extra green sectors was designed to study the effect of poor contrast between sectors. Conversely, the hue selection between sectors 13 to 16 was designed to maximise contrast. The names of the hues are subjective.

An important point to note is that there can be considerable variation in the appearance of colours between computer displays. For example, the 'greens' in Table 1 were clearly distinguishable on some computer monitors but were almost indistinguishable from each other on some other computer monitors. This is an effect caused by variations between commercial colour graphics cards and between monitors and demonstrates the necessity for all of the colour graphics within operational sonars of the one type to be provided by the same model of components from the one manufacturer. Operational systems need to be individually tuned to account for these minor variations so as to obtain maximum benefit.

RESULTS AND DISCUSSION

(a) Monochrome Displays

A series of monochrome displays based on various hues (red, yellow, green and light blue) were presented to each observer. No statistically significant difference in detection performance was found for any particular hue, as shown in Table 2. The averaged value is based on a total of 29 measurements: 3 aberrant data points caused by observer errors have been discarded. The theoretical DT assumes CG =0 in Eq. (2).

Monochrome Display Hue	Average Measured DT
Red	3.0 ± 1.1 dB
Green	2.4 ± 0.6 dB
Yellow	2.7 ± 0.7 dB
Light Blue	2.8 ± 1.1 dB
All displays combined	2.7 ± 0.9 dB
Theoretical DT: see Eq. (2)	1.7 ± 0.8 dB

Table 2. Average measured detection thresholds for the 8 human observers for each of the monochrome red, green, yellow and light blue displays and the average across all displays combined. All values of DT are normalised for PD = 0.5 and PFA = 10^{-4}. Uncertainties are one standard deviation.

(b) Polychrome Displays with Biased Noise

The next phase of the experiment studied the effect of contrast quality on detection performance for polychrome displays. Figures 2a and 2b show the average proportion of signals detected by the human observers as a function of bearing sector. Fig. 2a applies for broadband noise in sectors 1 through 8, while Fig. 2b applies for broadband noise arriving from sectors 9 through 16. The sectors showing the consistently better performance (especially sectors 14 and 15) are those where the colour hues were selected to maximise the contrast between sectors, while the detection performance in the 'green' sectors (7 to 11) where the contrast was relatively poor was not as good. Thus the consistency of the bearing resolution is directly affected by the selection of hues.

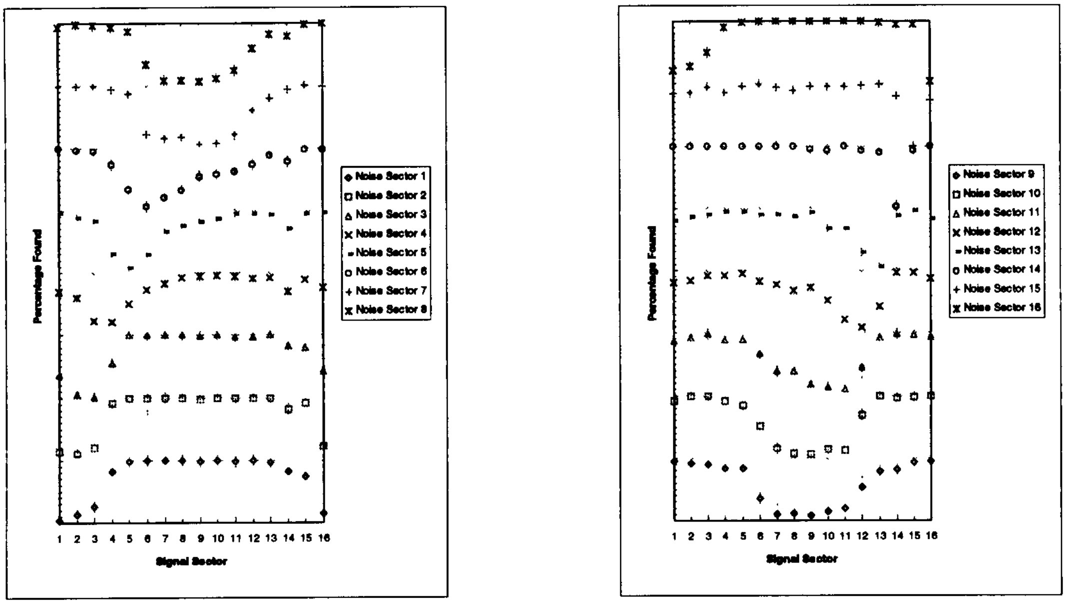

Figure 2a (left) and 2b (right). Average proportion of detected signals across all 8 human observers for various signal sectors for cases where the background noise is confined to just one sector (sectors 1 to 8 in 2a, sectors 9 to 16 in 2b). Each of the plots has been vertically offset so that the range between each adjacent pair of horizontal gridlines is 0% to 100%. The results have been compiled for various SNRs, but take no account of false alarm statistics.

(c) Signals and Noise in All Sectors

In this part of the experiment the observers were presented with signals from random sectors on a random noise background for each display. The detection threshold in this case can be directly compared with the earlier results using the monochrome displays. Table 3 shows the average measured detection thresholds of the 8 observers for the monochrome displays and for the polychrome displays. The averaged values of DT are based on 29 separate measurements (aberrations due to observer errors have been discarded). Also shown in Table 3 is the theoretical value for DT (with $CG = 0$), adjusted for the quantisation loss and with the effect of visual integration for human observers included as per Eq. (2).

	Detection Threshold
Theoretical ($CG = 0$)	1.7 ± 0.8 dB
Measured: Monochrome Display	2.7 ± 0.9 dB
Measured: Polychrome Display	1.5 ± 0.9 dB

Table 3. Theoretical and average measured DTs for the 8 human observers for the monochrome displays and the polychrome displays. All values of DT are normalised for PD = 0.5 and PFA = 10^{-4}. Uncertainties are one standard deviation.

Table 3 clearly shows an average improvement of 1.2 dB in detection threshold by the human observers using the polychrome displays compared to the monochrome displays. This difference in average DT is more than twice the size of a 99.9% confidence level for the number of measurements used and is clearly a systemic improvement rather than a statistical artefact. Indeed, this 'colour gain' represents a significant improvement in overall system performance when humans are used as observers and so this is a useful feature to incorporate in any new sonar display system. The colour gain measured here is consistent with the theoretical improvement of 1.5 dB for human observers suggested by Buratti, Rio and Witlin (Ref. 2), and is also consistent with the experimental observations made by those same authors using active sonar displays.

Figure 3 is a plot of the average percentage find rate of signals (left axis, with diamonds for data points) and the relative combined brightness of the three colour guns within the PC monitors (right axis, with squares for data points) plotted as a function of the signal sector. Here the find rate corresponds to the average PD of the group of observers across all SNRs, but takes no account of the false alarm statistics. There is a clear correlation between the signal find rate with the combined brightness for many sectors. This indicates that it is the relative brightness which dominates the signal detectability for human observers rather than the specific choice of colour hues. However, when the false alarm statistics are accounted for, it is clear that the extra detections are being accompanied by extra false alarms in order to yield similar values of the normalised DT for the various colours, as shown in Table 2. This result is consistent with the observation that monochrome displays, being based purely on relative luminance to indicate input SNR, have generally given what were considered to be satisfactory results in the past.

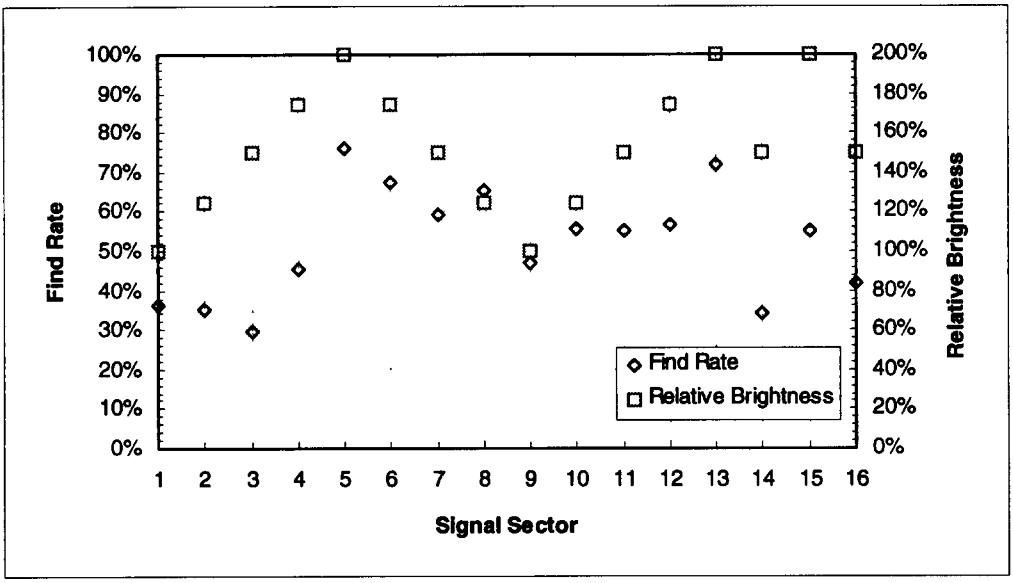

Figure 3. A plot of the average percentage find rate for the 8 human observers (left axis, diamond data points) and the relative brightness obtained by combining the intensities (0 to 100% each) of the red, green and blue colour guns (right axis, square data points) plotted as a function of signal sector.

CONCLUSION

This work has demonstrated the improvement in the detection threshold of a sonar system in which colour is used to convey directional information within a lofargram. The improvement in detection threshold was measured as being 1.2 dB, which represents a significant reduction in the 'human factors' loss normally associated with the use of human observers to make detection decisions with sonar systems. The reduction in this human factors loss is due entirely to the fact that the colour coding provides an additional source of information for the pattern recognition skills used by the human observers when they are examining the display to make signal detections.

All eight of the observers in this experiment obtained some degree of improvement in their average DT for the polychrome displays compared to the monochrome displays. This indicates the effect is relatively consistent across a group of observers and so the average improvement may confidently be factored into operations research modelling of the overall sonar system performance.

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