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Detection of Targets in Terrain Clutter by Using Multispectral Infrared Image Processing

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ADMINISTRATIVE INFORMATION

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SUMMARY

PROBLEM

Investigate a weighted-difference signal-processing algorithm for detecting ground targets by using dual-band IR data.

RESULTS

Three variations of the algorithm were evaluated: (1) simple difference; (2) minimum noise; and (3) maximum SNR. The theoretical performance was compared to measured performance for two scenes collected by the NASA TIMS sensor over a rural area near Adelaide, Australia, and over a wooded area near the Redstone Arsenal. The theoretical and measured results agreed extremely well. For a given correlation coefficient and color ratio, the amount of signal-to-noise ratio gain can be predicted. However, target input SNRs and color ratios can vary considerably. For the targets and scenes evaluated here, the typical gains achieved ranged from a few dB loss (targets without color) to a maximum of approximately 20 dB.
1.0 INTRODUCTION

The detection of small targets in clutter is a problem of critical importance to wide-area surveillance [1]. Stealth technology has made targets more difficult to detect. Targets can also hide in clutter that is either manmade or natural. One technology continuously being investigated for improving small-target detection in clutter is infrared (IR) imagery. Multispectral IR films have been effective for detecting some forms of camouflaged targets and other targets using false coloring [2]. Recently, interest in using multispectral sensor data in signal processing was stimulated by an analysis of such data collected by the NASA Thermal Infrared Multispectral Scanner (TIMS) sensor in Australia during 1985 [3]. These data and their analysis [4] suggested that multispectral processing techniques could greatly improve detection of small, hard-to-find targets.

The work presented here is part of the DARPA Multi-Spectral Infrared Camera (MUSIC) program. Several algorithms have been developed and tested on infrared data [5,6,7].

The objective of this work was to investigate weighted difference, a signal-processing algorithm for detecting ground targets by using dual-band IR data. This algorithm is derived, analyzed, and compared to empirically measured results.

Section 2.0 gives a derivation of the algorithm and its theoretical signal-to-noise ratio (SNR) of input to output. Section 3.0 gives the results of applying the algorithm to two image scenes, and compares the results to the theoretically predicted performance (showing excellent agreement). Numerical details supporting this work have been included in the appendices.

2.0 MULTISPECTRAL PROCESSING CONCEPTS

There are two principles we exploit in our use of multispectral IR imagery. The first is that IR images of natural backgrounds in different long-wave infrared (LWIR) bands tend to be highly correlated. This high degree of correlation allows the data collected in one spectral band to be used to cancel the background clutter in the data collected in another spectral band. The second principle involved is that the LWIR signatures of manmade objects generally do not exhibit the same relationship between bands as do the correlated background signatures. We refer to this difference in target signature between bands as "coloring."

The algorithm for weighted differences is the following: the scene data in one band are multiplied by a constant and subtracted from the scene data in the other spectral band on a pixel-by-pixel basis. The constant is chosen so that the background clutter in the resulting image is minimized. While the background is minimized, the target will leave some residual in the output image because of its coloring between spectral bands. Target coloring and background correlation determine the performance of the weighted-difference algorithm.

The output radiance for each band is the sum of target signal and background clutter. The background clutter is assumed to be made up primarily of natural vegetation or clouds (which are grey bodies), so the clutter will be highly correlated from one band to the next. Sensor noise and "colored," or nongrey, bodies in the image will reduce the correlation coefficient between the two bands. The targets are assumed to be manmade objects and are characterized as selective radiators, which can have a different radiance level, or color, in each band.

The sensor either scans or uses a focal-plane array to collect data in a rectangular image. The data consist of pixels that are modeled as being either target or background clutter. Each pixel records a measure of the received IR radiance for that image cell. The target pixel obscures the background, so these pixels contain only target radiance and no background.
Let the target pixel be given by $S_i$ and clutter pixels be labeled as $N_i$, where $i = x$ or $y$ for bands $x$ and $y$, respectively. The target radiance in the bands is given by

$$S_i = \varepsilon_{si} B(T) \quad i = x, y \quad (1)$$

and the background radiance is given by

$$N_i = \varepsilon_{ci} B(T_c) \quad i = x, y \quad (2)$$

where

- $T$ = the target temperature
- $T_c$ = the temperature of the background
- $\varepsilon_{si}, \varepsilon_{ci}$ = the emissivity coefficients for target and clutter
- $B$ = Planck’s black-body function.

$N_i$ is a random variable because of random variations from pixel to pixel of the emissivity and clutter temperature. Let $m_i$ and $\nu_i$ be the mean and variance of the clutter for band $i$. The standard deviation is the square root of the variance and will be denoted as $\sigma_i$. The correlation coefficient of the two bands is then given by

$$\rho = \frac{\text{Cov}(N_x, N_y)}{\sigma_x \sigma_y} \quad (3)$$

Figure 1 gives a block diagram for the weighted-difference algorithm. The algorithm multiplies the image from band $y$ by a constant weight, $\omega$, and subtracts it from the image from band $x$. The objective of the algorithm is to produce an output image that enhances the target signal-to-noise ratio. There are three variants of the algorithm, depending on how the constant, $\omega$, is derived.

Variant 1: Max_SNR

*Choose $\omega$ to maximize the output SNR.*

Variant 2: Min_Noise

*Choose $\omega$ to minimize the variance of the output image.*

Variant 3: Sim.Diff

*Choose $\omega = 1.0.*

Define the input pixel signal-to-noise ratio to be

$$\text{psnr}(i) = \frac{[\text{Targetpixel}(i) - m_i]}{\sigma_i} \quad (4)$$
The signal-to-noise ratio is measured in dB, given by the following

$$\text{SNR}_\text{in} \ (\text{dB}) = 10 \log [\text{psnr}(i)]^2$$  \hspace{1cm} (5)

where $i$ denotes the band.

Let $V$ be the output variance when only clutter is present; then the output signal-to-noise ratio that is to be optimized is $\text{SNR}_{out}$, where

$$\text{SNR}_{out} = \frac{(S_x - \omega S_y)^2}{V}.$$  \hspace{1cm} (6)

The output variance can be shown to be a function of the input statistics as

$$V = \sigma_x^2 - 2\omega \sigma_x \sigma_y + \omega^2 \sigma_y^2.$$  \hspace{1cm} (7)

The three variants of the weighted-difference algorithm can be derived from the above equation. However, the derivation is simpler and easier to implement if each channel is normalized to have mean equal to zero and variance equal to one. The output SNR becomes

$$\text{SNR}_{out} = \frac{(S_{nx} - \omega S_{ny})^2}{(1 - 2\omega \rho + \omega^2)}$$  \hspace{1cm} (8)

Figure 1. Processing flow for weighted-difference algorithm.
where

$$S_{ni} = \frac{(S_i - m_i)}{\sigma_i}, \quad i = x, y.$$  \hfill (9)

The weight for variant 1, $\omega_{\text{max\_SNR}}$, can be determined by taking the derivative of the $\text{SNR}_{\text{out}}$ with respect to $\omega$ and setting it to zero to find the critical points. There are two critical values (see appendix B). The one that maximizes the $\text{SNR}_{\text{out}}$ is variant 1:

$$\omega_{\text{max\_SNR}} = \frac{\rho - c}{1 - \rho c}.$$  \hfill (10)

where $c$ is defined as the ratio of the pixel signal-to-noise ratios,

$$c = \frac{\text{psnr}_{\text{min}}}{\text{psnr}_{\text{max}}}, \quad -1 \leq c \leq 1.$$  \hfill (11)

When $c = \rho$ the weight is zero. This can be interpreted to mean that, for the Max\_SNR algorithm, the two bands should not be combined and the best output image when $\rho = c$ is the input image from band $x$. Note also that, when $c = 1/\rho$, the weight is infinity. This can similarly be interpreted to mean that, for the Max\_SNR algorithm, the two bands should not be combined and the best output image when $c = 1/\rho$ is the input image from band $y$. To avoid potentially large values of $\omega$, the input bands were arranged so that band $x$ was always the band with the largest $\text{psnr}$.

To implement the Max\_SNR algorithm, we need to know the color ratio of the target pixels. For selective radiators, this ratio would not be known ahead of time. For the calculations here, we knew where the target pixels were and measured the color ratio from the actual data, which is not a very practical algorithm implementation. One could come up with some clever scheme to predict or estimate the color ratio, but it will be shown that the performance of the Max\_SNR is not sufficiently better than the other algorithms to warrant the effort. The other algorithms do not require this information, and are much simpler to implement. The Max\_SNR algorithm serves as an upper bound to the performance obtainable from a weighted-difference algorithm.

The weight for variant 2, $\omega_{\text{min\_noise}}$, can be determined by taking the derivative of that quantity and finding the value of $\omega$ that minimizes the denominator. There is only one solution for $\omega$ in this case which is

$$\omega_{\text{min\_noise}} = \rho.$$  \hfill (12)

The Min\_Diff algorithm does not require knowledge of the target color. However, the algorithm has a similar problem to Max\_SNR in that it must know which band has the largest input SNR. If this is unknown, the algorithm must be performed twice, once for $x$ hypothesized as the largest and once for $y$. Both outputs must be threshold tested for detection. The penalties for not knowing which channel has the largest input SNR are increased computation and either a higher false-alarm rate or a higher threshold value—which will reduce the number of detections.

The weight for the simple difference variant is simply

$$\omega_{\text{sim\_diff}} = 1.0.$$  \hfill (13)

The output $\text{SNR}_{\text{out}}$ for each variant can be found by substituting the appropriate solutions for $\omega$ back into equation (8). Table 1 summarizes the three variants of the weighted-difference algorithm.
Table 1. Variants of the weighted-difference algorithm.

<table>
<thead>
<tr>
<th>Case</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1: Max_SNR</td>
<td>$\omega = \frac{\rho - c}{1 - \rho c}$</td>
</tr>
<tr>
<td>SNR</td>
<td>$\frac{S_1^2}{\sigma_1^2} \cdot \frac{(1 - \omega)^2}{1 - 2\omega + \omega^2}$</td>
</tr>
<tr>
<td>Case 2: Min_Noise</td>
<td>$\omega = \rho$</td>
</tr>
<tr>
<td>SNR</td>
<td>$\frac{S_1^2}{\sigma_1^2} \cdot \frac{(1 - \rho)^2}{1 - \rho^2}$</td>
</tr>
<tr>
<td>Case 3: Sim_Diff</td>
<td>$\omega = 1.0$</td>
</tr>
<tr>
<td>SNR</td>
<td>$\frac{S_1^2}{\sigma_1^2} \cdot \frac{(1 - \omega)^2}{2(1 - \rho)}$</td>
</tr>
</tbody>
</table>

Figure 2 is a plot of the theoretical output SNR for a band-to-band correlation coefficient of $\rho = 0.9$. The dB gain is very dependent on the color ratio. When the color ratio is 1, there is no color to the target. When the color ratio is negative, the target contrasts in the two bands have opposite signs; i.e., the target in one band is above its mean level and the target in the other band is below its mean level. The gain from these multispectral algorithms is greatest for negative color ratios. This is an important point since, for this to occur, the target must be near zero contrast and difficult to detect by spatial processing alone.

Figure 2. Weighted-difference algorithm variants for a background band-to-band correlation of 0.9.
Figure 3 shows three cases of interest. The first shows the radiance levels when the target appears hot compared to the background mean level. In this case, the input SNRs are positive and large (for this simple argument, the variance of the background about the mean level is not shown). The SNRs in the two channels are different only by the factor of the emissivity. Thus the ratio, $c$, will be positive and close to 1. In case 2, the input signal-to-noise ratios are small because they are close to the background mean level. Here the ratio of the SNRs can be magnified, depending on the mean level. The ratio of the SNRs could be large and possibly negative. This condition results in large SNR gain. In case 3, the target appears cold compared to the background. If the SNRs are large (but negative), the ratio again will be positive and close to 1. This results in a small gain.

Figure 4 is a theoretically derived curve comparing the output SNR from a spatial-differenced system with the best input SNR. The model parameters were arbitrarily chosen, but the figure illustrates the behavior of the differenced algorithm. It tends to provide gain when the input SNR is small. This characteristic “fills in” the SNR output curve when the input SNR is small.

### 3.0 COMPARISON OF THEORETICAL AND EXPERIMENTAL RESULTS

In this section, the theoretical performance is compared to measured performance for two multispectral infrared scenes collected by the NASA TIMS sensor. The first scene was collected over a rural area near Adelaide, Australia, and the second scene was collected over a mixed wooded and open-field area near the Redstone Arsenal in Huntsville, Alabama. The TIMS sensor has six channels between 8 and 12 μm; however, only two were used for weighted-difference application. Scenes were selected that were $512 \times 512$ and $256 \times 256$ pixels in dimension for the Adelaide scene and $256 \times 256$ for the Redstone scene. Each scene contains a number of manmade objects in a cluttered background that served as targets. There were 52 objects (houses, farm buildings, watertanks, etc.) in the Adelaide $512 \times 512$ scene that were declared targets and used to evaluate the dB gains as a function of the input SNR and detection statistics. There were 14 declared targets in the Adelaide $256 \times 256$ image that were used to evaluate SNR statistics. The analysis was repeated on the Redstone scene; however, this time military tanks (M60 and M48) were located in the scene as part of the experiment. The Redstone scene was used to confirm the results achieved by using the Adelaide data.

#### 3.1 EXPERIMENTAL RESULTS FROM THE ADELAIDE SCENE

The TIMS Australian data set was acquired as part of a joint U.S and Australian measurements program conducted in the fall of 1985 over several regions of Australia. The data set was obtained from a C-130 aircraft at a variety of altitudes. A review of the data taken during this particular acquisition found a rural natural background area in the hills east of Adelaide. A subsection of this area containing structures was selected for spectral processing [6].

Figure 5 is a grey-level image of the Adelaide $256 \times 256$ scene. The C-130 flew at a low altitude, which resulted in a ground resolution of 2.5-meter pixels. Channels 1 and 5 were selected for processing because they gave the best target color ratios and band-to-band clutter correlation. Figure 6 shows the output scene from the weighted-difference algorithm. The minimum noise variant with full preprocessing (i.e., line-by-line normalization and high-pass filtering) was used. Note that the output targets can have positive (bright) or negative (dark) contrast. Details of the numeric results are given in appendix A.
Figure 3. Three cases of relative target and background temperatures.
Band #1 = 8.2-8.6μm
Band #2 = 9.4-10.2μm
Clutter at 290*K

Rad sigma (σ) = 8% of B(290)

\[ \text{psnr}(i) = \frac{[\text{Targetpixel}(i) - m_i]}{\sigma_i} \]

SNR (dB) = 10 log[\text{psnr}(i)]^2

Let \( \varepsilon_{t1} = 0.80 \), effective emissivity of target in band 1
Let \( \varepsilon_{t2} = 0.99 \), effective emissivity of target in band 2
Assume \( \varepsilon_{cl} = 1.0 \), where \( \varepsilon_{cl} \) is emissivity of background

Band-to-band correlation coefficient \( \rho = 0.9 \).

Figure 4. Channel radiance versus temperature.
A rural area near Adelaide, South Australia, consisting of scattered trees, a forested region, rolling hills, and manmade structures. The image has 256 \times 256 pixels that have 2.5-meter ground resolution. Channels 1 and 5 were used for multispectral processing.

Figure 5. Adelaide scene.
Minimum noise variant used with line-by-line normalization and high-pass filter preprocessing.
Fourteen output targets are single pixels that are either bright or dark.

Figure 6. Adelaide—weighted-difference output.
The results of processing the Adelaide 256 × 256 data are compared to the theoretical output signal-to-noise ratio in figures 7a and 7b. First the multispectral images were processed without preprocessing and the results are shown in figure 7a. The signal-to-noise gain, measured in dB, is plotted as a function of the color ratio. The correlation coefficient for the Adelaide scene was 0.9929. There are three curves on the graph that are the theoretically predicted gain for the three variants of the weighted-difference algorithm. The symbols represent measured gain on targets in the Adelaide scene. There is excellent agreement between the theory and measured results.

Similarly, figure 7B presents the same information, except that in this case the data set was preprocessed as shown in figure 1. The signal-to-noise ratio gain is measured from the input to the output of the weighted difference algorithm, and does not include the SNR gain or loss caused by the preprocessing. In general, the weighted difference gains are much lower with preprocessing than without preprocessing, as can be seen by comparing the results to the example in figure 7. The reason for the drop in gain is that the preprocessing has reduced both the band-to-band correlation and the color ratio. However, the preprocessing also provides gain, so the overall effect is a net improvement over no preprocessing. The output signal-to-noise ratio level for preprocessing and no preprocessing are summarized in tables A4 through A6 of appendix A. With a few exceptions, the combination of preprocessing and weighted difference improved the overall output signal-to-noise ratio by 1 or 2 dB. The significant conclusion from figures 7a and 7b is that the SNR performance of the weighted-difference algorithm can be predicted.

Figure 8 shows the output signal-to-noise ratio plotted versus the input average pixel-to-noise ratio. The pixel signal-to-noise ratio is given by equation (4). The average psnr is a function of the difference between the target and the mean background temperatures. Using measured data from the Adelaide 512 × 512 scene (see appendix C), figure 8 compares the best input signal-to-noise ratio to the min_noise (without preprocessing) output SNR. The data have the same trend as the theoretical data shown in figure 4. The data are not smooth because the targets do not have the same emissivity, which causes the gain to vary for targets even at the same temperature. Regardless, the gain appears to be maximum near zero, as in figure 4, and shows the characteristic of the weighted-difference algorithm to "fill in" the output SNR when the target is small because of marginal target temperature difference from the background.

The detection statistics for the 52 targets in the Adelaide 512 × 512 scene were computed for 10⁻³ and 10⁻⁴ false-alarm rates, and the results are summarized in table 2. Details of the numeric results are provided in appendix C. The threshold for the false-alarm rates was computed from the data after the 52 targets were omitted from the 512 × 512 image. As shown in figure 8, the performance improvement of the weighted-difference algorithm depends on the relative target temperature to the average background temperature as well as the target emissivity. Thus the number of detections in table 2 depend on the statistical distribution of the target temperature and emissivity provided in the Adelaide scene.

<table>
<thead>
<tr>
<th>Processing Algorithm (Bands 1 and 5)</th>
<th>Detections at CFAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10⁻³</td>
</tr>
<tr>
<td>No Preprocessing</td>
<td></td>
</tr>
<tr>
<td>Band 5—Raw Input</td>
<td>28</td>
</tr>
<tr>
<td>Simple Difference</td>
<td>44</td>
</tr>
<tr>
<td>Minimum Noise</td>
<td>45</td>
</tr>
<tr>
<td>Preprocessed</td>
<td></td>
</tr>
<tr>
<td>Band 5</td>
<td>34</td>
</tr>
<tr>
<td>Simple Difference</td>
<td>47</td>
</tr>
<tr>
<td>Minimum Noise</td>
<td>47</td>
</tr>
</tbody>
</table>

Table 2. Detection statistics for 52 targets in the Adelaide scene.
Actual data points from the Adelaide 256 × 256 scene plotted on the theoretical curves for the three variants of the weighted-difference algorithm.

Figure 7a-b. dB gain as a function of color ratio.
Actual data points from the Adelaide 512 x 512 scene. Compare with figure 4.

Figure 8. dB gain as a function of input SNR.
Without any processing, 28 of the 52 targets could be detected at a $10^{-3}$ false-alarm rate. With full preprocessing and the minimum-noise-difference algorithm, this number was increased to 47. The detection rate improvement from 54% to 90% is a very significant result.

### 3.2 EXPERIMENTAL RESULTS FROM THE REDSTONE SCENE

The Redstone experiment was performed on 9 March, 1989, at Redstone Arsenal, Alabama, using the TIMS sensor. A Lear Jet was flown during two time periods, 0800 to 0900 and 1100 to 1200 h. A data set was taken during each of these flights at three different altitudes, resulting in a resolution of 2.5, 5, and 10 meters. The weather was clear, with a slight breeze and moderate haze that burned off during the morning. The air temperature increased from 39 to 51°F.

The experimental setup was located at Redstone Arsenal's Test Area No. 3, which consists of slightly rolling hills with a grass-covered stretch of land surrounded by loblolly pines and deciduous trees. The grass was disturbed as a result of tank movements in the field. Three tanks were set up as targets, and nearby temporary buildings and a concrete pad located to the south of the tanks were used as targets of opportunity. Tank A, an M48, was located on the edge of the field with trees just to the west. Tank B, an M60, was under the trees on a dirt road covered with pine needles. The trees provided about a 50% canopy over the tank. Tank C, another M48, was located in the open field. The ground was less disturbed around tank C than tank A. Tank B, the tank under the trees, was not observed with the infrared sensor or high-resolution photography.

Both tank A and tank C were detected in the 2.5-m data by means of several algorithms in both the morning and noon scenes. Tank C, the open-area tank, was also detected in the lower-resolution data. In this section, we will concentrate on the detections made during the early-morning 2.5-m scene, with particular emphasis on the tree-line tank A. A gray-level image of the scene showing the tank locations is given in figure 9.

Bands 1 and 4 of the TIMS data were spectrally processed and the detailed numeric results are given in appendix D. Bands 1 and 4 were chosen since they show spectral color. The results for a 32 $\times$ 32 image centered on the tree line of tank A are shown in figure 10. The tree-line tank, not discernible in the input data in figure 10A, can be seen easily in figure 10B.

The location of a target detection relative to false alarms is an important indication of algorithm performance, since a constant false-alarm rate system would need to suppress false alarms to a specified level. The cumulative distributions for the unprocessed input and processed data are shown in figures 11a and 11b. Tank A and C pixels were removed before calculating the distributions. The curves can be used to estimate the false-alarm rate that would result for a given threshold decision level. For unprocessed input data, the false-alarm rate would have to be $2 \times 10^{-1}$ before the target could be detected. After processing, a more reasonable false-alarm rate of only $7 \times 10^{-5}$ would have to be tolerated. (Recall that, if the strongest input channel were not known a priori, a double-sided threshold would be required). The double-sided threshold could double the number of false alarms to $1.4 \times 10^{-4}$, which is still a reasonable value. The false alarms at thresholds greater than tank A were caused by man-made structures (concrete pad, buildings, vehicles) in the scene, which were also colored. These man-made objects can be considered as targets in the context of a natural scene.

The various colored, manmade objects in the scene can be used to verify the theory presented earlier. The output depends on the amount of target coloring [see equations (8) and (10)]. Each of these objects has a different color ratio. These objects were identified by means of site visits and aerial photography. The objects investigated included two structures, two pixels on tank C, tank A, and a rectangular concrete pad.
Scene consists of slightly rolling hills, with a grass-covered stretch of land surrounded by loblolly pines and deciduous trees.

Figure 9. Huntsville, Alabama—Redstone scene.
(a) Channel 4 input image; SNR = -0.93 dB.

(b) Minimum noise channels 1 and 4 output image; SNR = 15.31 dB. (Preprocessed data: normalized line by line, high pass filtered, and globally normalized.)

Figure 10. Huntsville, Alabama—Redstone 2.5-m tree-line tanks.
FALSE-ALARM STATISTICS, REDSTONE TANK SCENE, CHANNEL 4 INPUT

Figure 11a-b. Cumulative distributions for the unprocessed input data and preprocessed MIN_NOISE 1 and 4 output data.
These results are presented for the three algorithm variants in figure 12. The solid lines of figure 12 are plots of the theoretical output SNR for a band-to-band correlation coefficient of $\rho = 0.9$. The dB gain is very dependent on the color ratio. When the color ratio is 1, there is no color to the target. When the color ratio is negative, the target contrasts in the two bands have opposite signs; i.e., the target in one band is above its mean level and the target in the other band is below its mean level.

The symbols represent data points taken from targets in the Redstone scene. For these data points, the gain is plotted against the input color ratio. The data set shows an excellent match to the theory.

![SNR dB GAIN FOR SPATIAL DIFF BAND-TO-BAND CORREL COEFF 0.9](image)

Actual data points from the Redstone scene plotted on the theoretical curves for the three variants of the weighted-difference algorithm. For this data set, preprocessing was not performed.

Figure 12. dB gain as a function of color ratio.

4.0 CONCLUSIONS

In this report, the weighted-difference algorithm was derived, analyzed, and compared to measured data. Three variants of the algorithm were evaluated: (1) simple difference; (2) minimum noise; and (3) maximum output SNR. The variants require increasing amounts of prior information to be implemented. Although the corresponding performance of the variants also increases, the increase is very small for targets that are in the detectable range of input SNR and color ratio.

The performance of the weighted-difference algorithm depends on the correlation coefficient between the two spectral bands, the ratio of the target pixels (color ratio), and the input target's
signal-to-noise ratio. In this report, the theoretical performance has been compared to measured performance for two scenes. The scenes were collected by the NASA TIMS sensor over a rural area near Adelaide, Australia and over a wooded area near the Redstone Arsenal. Scenes were selected that were $512 \times 512$ and $256 \times 256$ pixels in dimension and contained a number of targets in a cluttered background. There were 52 objects (buildings, watertanks, etc.) in the Adelaide $512 \times 512$ scene that were declared targets and used to evaluate the dB gain as a function of input SNR and detection statistics. There were 14 declared targets in the Adelaide $256 \times 256$ image that were used to evaluate SNR statistics. The analysis was repeated on the Redstone scene; however, this time there were military tanks (M60 and M48) in the scene. The Redstone scene was used to confirm the results achieved by using the Adelaide scene.

The theoretical and measured results agree extremely well. For a given correlation coefficient and color ratio, the amount of signal-to-noise ratio gain can be predicted. However, target input SNRs and color ratios can vary considerably. For the targets and scenes evaluated here, the typical gains achieved ranged from a few dB loss (targets without color) to a maximum of approximately 20 dB.

REFERENCES


APPENDIX A: DETAILS OF NUMERIC RESULTS, ADELAIDE DATA SET

The TIMS Adelaide data set was processed to compare the results to the spatial difference model developed by L. E. Hoff. The first step in this processing was to determine which two of the six TIMS bands met the criterion of high correlation between the bands. A routine was run on the raw data that produces a correlation coefficient matrix as shown in figure A-1. It was also desirable for this processing that the bands be widely separated, which tends to preserve target coloring. Bands 1 and 5, with a correlation coefficient of 0.9929, were chosen.

\[
\begin{pmatrix}
1.000 & 0.996 & 0.995 & 0.994 & 0.993 & 0.986 \\
0.996 & 1.000 & 0.996 & 0.995 & 0.993 & 0.986 \\
0.995 & 0.996 & 1.000 & 0.994 & 0.991 & 0.983 \\
0.994 & 0.995 & 0.994 & 1.000 & 0.995 & 0.985 \\
0.993 & 0.993 & 0.991 & 0.995 & 1.000 & 0.990 \\
0.986 & 0.985 & 0.983 & 0.985 & 0.990 & 1.000
\end{pmatrix}
\]

Figure A-1. Correlation coefficient matrix.

The second step in the processing was to window the area of interest. An area that was 256 x 256 in size was chosen. From this area, 14 target pixels were chosen for this processing run. Figure A-2 identifies the target pixels by line and column.

<table>
<thead>
<tr>
<th>Pixel Name</th>
<th>Line</th>
<th>Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1a</td>
<td>133</td>
<td>50</td>
</tr>
<tr>
<td>a1b</td>
<td>133</td>
<td>51</td>
</tr>
<tr>
<td>a2a</td>
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<tr>
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</table>

Figure A-2. Adelaide target pixels.

Figure A-3 outlines the processing steps used on the 256 x 256 image. This diagram shows the general data flow but does not show the switches that can be made in preprocessing of the data. Three different preprocessing methods were used on this data set. The first case did a global processing.
normalization on the image, which took the mean and variance of the entire 256 × 256 image to compute pixel values. The second case did a line-by-line normalization on the data, which entailed taking the mean and variance of each line to determine the pixel values of each, and then doing a global normalization on the data. The third case did a line-by-line normalization on the data, followed by a high-pass, 5 × 5 filter on the data. As a last step, the data set was globally normalized. The final output of the preprocessing phase of this image processing consisted of six files, three each of band 1 and band 5, globally normalized, line-by-line normalized, and filtered.

For each case, and at each target pixel, the band with the largest signal-to-noise (SNR) was determined and this data set was entered into a database (see tables A-1, A-2, and A-3). The pixel values that determined the color ratio for comparison purposes were also entered at this time.

On completion of the preprocessing steps, there were three weighted-difference algorithms applied to each set (band 1 and band 5) of data. Each of these algorithms used a different weighting factor; one maximized the output SNR, one minimized the noise, and one used a weighting factor of 1. These algorithms are referred to as Max_SNR, Min_Noise, and Sim_Diff (simple difference). The Min_Noise algorithm was applied twice to each data set. One run applied band 1 to band 5, and the second run applied band 5 to band 1. The SNR for each target pixel from each output image was then measured and entered into the database with the input band’s SNRs (tables A-1 through A-3). The dB gain was then computed from the input and output SNR information and entered into the database. The data provided the necessary information for comparing the spatial-difference model to the Adelaide data.

Tables A-4, A-5, and A-6 consolidate the SNR data for each weighted difference algorithm for quick-look purposes.
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<th>NAME</th>
<th>LINE</th>
<th>PIXEL</th>
<th>GB</th>
<th>SR IN</th>
<th>SR OUT (IN DB)</th>
<th>COLOR</th>
<th>PFM-SNR IN</th>
<th>BK-SNR IN</th>
<th>RATIOS</th>
<th>PIXEL VALUE</th>
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Table A.1: Adelaide normalized (entire image only) target data.
Table A-2. Adelaide normalized (line by line, then entire image) target data.

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<th>PIXEL VALUE</th>
<th>COLOR</th>
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<th>dB GAIN</th>
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Table A-3. Adelaide (normalized line by line/high-pass filter/then renormalized) target data.

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<th>FM&lt;SNRIN</th>
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<th>MIN 1-5</th>
<th>MIN 5-1</th>
<th>SIMP SNR</th>
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Table A-4. SNRs for various processing (normalized only, normalized line by line, filtered) maximum SNR—Adelaide channels 1 and 5 (8/15/90).

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<th>NORMALIZED WHOLE IMAGE</th>
<th>NORMALIZED LN X LN</th>
<th>FILTER</th>
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Table A-5. SNRs for various processing (normalized only, normalized line by line, filtered) minimum noise—Adelaide channels 1 and 5 (8/15/90).

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<th>NORMALIZED LN X LN</th>
<th>FILTER</th>
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Table A-6. SNRs for various processing (normalized only, normalized line by line, filtered) simple difference—Adelaide channels 1 and 5 (8/15/90).

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<th>PIXEL</th>
<th>BAND</th>
<th>&gt; SNR IN (dB)</th>
<th>NORMALIZED WHOLE IMAGE</th>
<th>NORMALIZED LN X LN</th>
<th>HIGH PASS FILTER</th>
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APPENDIX B: MODEL FOR TWO-CHANNEL SYSTEM

The following is a model for a two-channel system. Let

\[ R_k = S_k \text{ or } N_k \quad k = 1, 2 \]

be the received radiance in band \( k \). If signal is present, the background, \( N_k \), is occluded. The spatial difference algorithm is formulated as

\[ d(R) = R_1 - \omega R_2 . \]

For the signal pixel(s), we get

\[ d(S) = S_1 - \omega S_2 \]

and for the background pixels (noise and clutter), we get

\[ d(N) = N_1 + \omega N_2 . \]

The output SNR is defined as follows

\[ \text{SNR} = \frac{|d(S)|^2}{\text{var}[d(N)]} . \]

Assume that each channel input has been normalized so that image mean is zero and the variance is 1.0. Define the following two parameters:

\[ c = \frac{S_2}{S_1} , \quad \text{where } S_2 < S_1 , \quad -1 < c < 1 \]

\[ \rho = \frac{\text{Cov}[N_1, N_2]}{\sigma_1 \sigma_2} . \]

First, let us derive the SNR:

\[ \text{var}[d(N)] = E[(N_1 - \omega N_2)^2] \]

\[ = E[N_1^2 - 2\omega N_1 N_2 + \omega^2 N_2^2] \]

\[ = \sigma_1^2 - 2\omega \rho \sigma_1 \sigma_2 + \omega^2 \sigma_2^2 \]

\[ = 1 - 2\omega \rho + \omega^2 \]

and

\[ S_{ni} = \frac{(S_i - m_i)}{\sigma_i} \quad i = 1, 2 \]

giving

\[ \text{SNR} = \frac{(S_{n1} - \omega S_{n2})^2}{(1 - 2\omega \rho + \omega^2)} = \frac{S_{n1}^2 (1 - \omega c)^2}{1 - 2\omega \rho + \omega^2} . \]
We derive \( \omega \) three ways: (1) choose \( \omega \) to maximize SNR; (2) choose \( \omega \) to minimize \( \text{Var}[d(N)] \); (3) choose \( \omega \) equal to 1. To find the \( \omega \) that maximizes the SNR, we perform the following derivations:

\[
\frac{\partial \text{SNR}}{\partial \omega} = \frac{2S_{n1}^2(1 - \omega c)(-c)}{1 - 2c \rho + \omega^2} + \frac{S_{n1}^2(1 - \omega c)^2}{(1 - 2c \rho + \omega^2)^2} (2\omega - 2\rho)(-1)
\]

\[
= \frac{-S_{n1}^2(1 - \omega c)}{1 - 2c \rho + \omega^2} \left[ 2c + \frac{(1 - \omega c)(2\omega - 2\rho)}{1 - 2c \rho + \omega^2} \right]
\]

\[
= \frac{-2S_{n1}^2(1 - \omega c)}{1 - 2c \rho + \omega^2} \left[ c + \frac{(1 - \omega c)(\omega - \rho)}{1 - 2c \rho + \omega^2} \right].
\]

The above equation has two zeros. The first one, easily seen in the first term, is \( \omega = 1/c \). The second one is derived as follows:

\[
\frac{(1 - \omega c)(\omega - \rho)}{1 - 2c \rho + \omega^2} + c = \frac{\omega - \omega^2 c - \rho + \omega c \rho + c - 2c \rho c + \omega^2 c}{1 - 2c \rho + \omega^2}
\]

\[
= \frac{\omega + c - \omega c \rho - \rho}{1 - 2c \rho + \omega^2}
\]

\[
= \frac{\omega(1 - c \rho) + c - \rho}{1 - 2c \rho + \omega^2}
\]

which, when we set equal to zero, gives

\[
\omega = \frac{\rho - c}{1 - \rho c}.
\]

The first term gives a minimum, the second a maximum. Figure B-1 is a plot of \( \text{SNR} \) as a function of \( \omega \), showing the maximum and minimum. This plot has \( \rho \) equal to 0.99 and \( c \) equal to 0.9. For case 2 we take the derivative of the noise term with respect to \( \omega \).

\[
\frac{\partial \text{Var}[d(N)]}{\partial \omega} = -2\rho - 2\omega \Rightarrow \rho = \omega
\]

and

\[
\text{SNR} = S_{n1}^2 \frac{(1 - \rho c)^2}{1 - \rho^2}.
\]

For case 3, we just set \( \omega = 1 \), giving

\[
\text{SNR} = S_{n1}^2 \frac{(1 - c)^2}{2(1 - \rho)}.
\]

B-2
Figure B-1. SNR as a function of $\omega; \rho = 0.99$, $c = 0.90$. 
APPENDIX C: ANALYSIS OF DATA, ADELAIDE
512 × 512 SCENE

The TIMS Adelaide 512 × 512 data set was analyzed to evaluate detection statistics for 10^{-3} and 10^{-4} false-alarm rates as a follow-on to investigation of weighted-difference signal-processing algorithms for detecting ground targets by using dual-band IR data. Extensive investigation of these algorithms was done by using the TIMS Adelaide 256 × 256 data set; however, for determining detection statistics, the TIMS Adelaide 512 × 512 image was chosen because it contained significantly more targets. Figure C-1 identifies these targets by row and column number.

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<th>Pixel Name</th>
<th>Line</th>
<th>Pixel</th>
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Figure C-1. TIMS Adelaide 512 × 512 image targets.

The detection statistics were determined for two sets of data: data that had not been preprocessed and preprocessed data. The preprocessed data set was line-by-line normalized, filtered with a high-pass filter, and then globally normalized. There were two weighted-difference algorithms, simple difference and minimum noise, applied to each set.

Histograms were formed for each image after omitting the 52 targets. Two accumulated statistics were obtained for each histogram: ascending values and descending values. These accumulated statistics were used to estimate the false-alarm rate associated with each target. The threshold for the false-alarm rates was then obtained from the data. Attachment (1), which follows table C-10, contains the numeric results of this computation. At the predetermined thresholds of 10^{-3} and 10^{-4}, the number of detections that occurred was determined by using previously measured pixel values in tables C-1 through C-10. This determination included targets that were positive, with a pixel value larger than the...
image mean, and negative targets, with a pixel value less than the mean. Figure C-2 summarizes the results.

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Figure C-2. Detection statistics for 52 targets in the Adelaide scene.
Table C-1. Channel 1, no preprocessing.

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APPENDIX D: DETAILS OF NUMERIC RESULTS, HUNTSVILLE DATA SET

The TIMS Huntsville data set was processed to confirm results achieved by using the TIMS Adelaide data set. The TIMS Adelaide data set was processed to compare the results to the spatial difference model developed by L. E. Hoff.

The first step in this processing was to determine which two of the six TIMS bands met the criterion of high correlation between the bands. A routine was run on the raw data that produces a correlation coefficient matrix, as shown in figure D-1. It was also desirable for this processing that the bands be widely separated, which tends to preserve target coloring. Bands 1 and 4, with a correlation coefficient of 0.9015, were chosen.

\[
\begin{pmatrix}
1.000 \times 10^0 & 9.750 \times 10^{-1} & 9.376 \times 10^{-1} & 9.015 \times 10^{-1} & 8.300 \times 10^{-1} & 7.647 \times 10^{-1} \\
9.750 \times 10^{-1} & 1.000 \times 10^0 & 9.374 \times 10^{-1} & 8.827 \times 10^{-1} & 7.938 \times 10^{-1} & 7.315 \times 10^{-1} \\
9.376 \times 10^{-1} & 9.374 \times 10^{-1} & 1.000 \times 10^0 & 8.034 \times 10^{-1} & 7.314 \times 10^{-1} & 5.921 \times 10^{-1} \\
9.015 \times 10^{-1} & 8.827 \times 10^{-1} & 8.034 \times 10^{-1} & 1.000 \times 10^0 & 9.625 \times 10^{-1} & 8.958 \times 10^{-1} \\
8.300 \times 10^{-1} & 7.938 \times 10^{-1} & 7.314 \times 10^{-1} & 9.625 \times 10^{-1} & 1.000 \times 10^0 & 9.084 \times 10^{-1} \\
7.647 \times 10^{-1} & 7.315 \times 10^{-1} & 5.921 \times 10^{-1} & 8.958 \times 10^{-1} & 9.084 \times 10^{-1} & 1.000 \times 10^0 \\
\end{pmatrix}
\]

Figure D-1. Correlation coefficient matrix.

The second step in the processing was to window the area of interest. An area that was 256 \times 256 in size was chosen. From this area, 22 target pixels were chosen for this processing run. Figure D-2 identifies the target pixels by line and column.

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Figure D-2. Huntsville target pixels.

Three different preprocessing methods were used on this data set. The first case did a global normalization on the image, which took the mean and variance of the entire 256 \times 256 image to
compute pixel values. The second case did a line-by-line normalization on the data, which entailed
taking the mean and variance of each line to determine the pixel values and then doing a global
normalization on the data. The third case did a line-by-line normalization on the data, followed by a
high-pass $5 \times 5$ filter. As a last step, the data set was globally normalized. The final output of the
preprocessing phase of this image processing consisted of six files, three each of band 1 and band 4,
globally normalized, line-by-line normalized, and filtered.

For each case, and at each target pixel, the band with the largest signal-to-noise (SNR) was
determined and the data set was entered into a database (see tables D-1, D-2, and D-3). The pixel
values that determined the color ratio for comparison purposes were also entered at this time.

Upon completion of the preprocessing steps, three weighted-difference algorithms were applied to
each set (band 1 and band 4) of data. Each of these algorithms used a different weighting factor; one
maximized the output SNR, Max_SNR; one minimized the noise, Min_Noise; and one used a weight-
ing factor of 1, Sim_Diff. The Min_Noise algorithm was applied twice to each data set. One run
applied band 1 to band 4; the second run applied band 4 to band 1. The SNR for each target pixel
from each output image was then measured and entered into the database with the input band’s SNRs
(Tables D-1 through D-3). The dB gain was then computed from the input and output SNR informa-
tion and entered into the database. The data provided the necessary information for comparing the
spatial-difference model to the Huntsville data.
Table D-2. Huntsville normalized (line by line, then entire image) channels 1 and 4 target data.

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Table D.3. Huntsville normalized (line by line/row filters then renormalized) channels 1 and 4 target data.

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<th>&gt; SIR IN</th>
<th>PIXEL VALUE</th>
<th>COLOR</th>
<th>MAX SIR</th>
<th>MIN SIR</th>
<th>MIN SIR (in dB)</th>
<th>MAX SIR (in dB)</th>
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<tr>
<td>T2</td>
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<tr>
<td>T3</td>
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D-5
**DETECTION OF TARGETS IN TERRAIN CLUTTER BY USING MULTISPECTRAL INFRARED IMAGE PROCESSING**

L. E. Hoff, J. R. Evans, and L. E. Bunney

Naval Ocean Systems Center (Code 765)
San Diego, CA 92152-5000

Approved for public release; distribution is unlimited.

A weighted-difference signal-processing algorithm for detecting ground targets by using dual-band IR data was investigated. Three variations of the algorithm were evaluated: (1) simple difference; (2) minimum noise; and (3) maximum SNR. The theoretical performance was compared to measured performance for two scenes collected by the NASA TIMS sensor over a rural area near Adelaide, Australia, and over a wooded area near the Redstone Arsenal. The theoretical and measured results agreed extremely well. For a given correlation coefficient and color ratio, the amount of signal-to-noise ratio gain can be predicted. However, target input SNRs and color ratios can vary considerably. For the targets and scenes evaluated here, the typical gains achieved ranged from a few dB loss (targets without color) to a maximum of approximately 20 dB.
<table>
<thead>
<tr>
<th>L.E. Hoff</th>
<th>(619)553-6186</th>
</tr>
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</table>
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