Refraction occurs when there is a sound speed gradient as a function of height. Typically this occurs when there is a wind or when there is solar ground heating. The effect of refraction is better sound propagation when the receiver is downwind of a source, or when the ground is cooler than the air. This can occur in the evening after a hot day. Conversly, when the receiver is upwind of a source, or on a hot afternoons, very little of the sound will reach the receiver. The energy received in an upward refracting environment can be as much as ten times less than in a downward refracting environment.

The geometry of a small arms fire event has an important impact on the signals at a receiver. Figure 5 shows that the sound measured at the receiver is composed of three contributions: direct wave, reflected wave and ground wave. If there are objects around the receiver, then there are also reflections from the objects. A detector must distinguish these reflections from real shot events. The direct and reflected waves superimpose at the receiver, and can cancel if the source and receiver are close to the ground. The ground wave is the result of the spherical wavefront interacting with a porous ground that is not a perfect reflector. Effectively porous ground acts as a low-frequency filter. Soft ground such as snow, sand or grass will transform the acoustic energy into a long-lasting pulse containing only low frequencies[2].

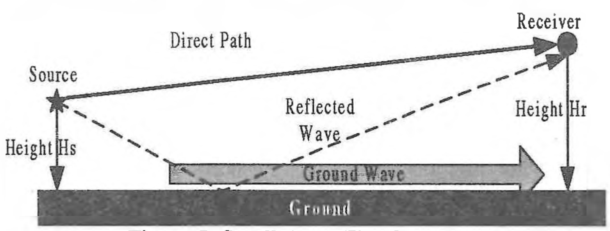

Figure 5: Small Arms Fire Geometry.

The great variety of environmental conditions turns the sound pulses into a continuum of shapes and durations which require compromises during pattern recognition. The acoustic wave in Figure 1 is an example of a situation where the direct and reflected waves do not cancel. The rapid oscillations at the beginning of the figure are the direct and reflected waves, while the wide peak that follows them is due to the ground wave.

4. Detection Techniques

There are several detection methods that are well suited to wide band transients. The simplest of these is an energy detector, which can be improved by filtering the signal into different bands of interest if appropriate. Other detection methods considered were short-time fourier transform (STFT), wavelet transform (WT), and matched filter processing.

As expected, the STFT detector is best suited to narrowband transients since it concentrates energy into narrow frequency bins. The WT detector concentrates energy in 'bins' that correspond to scaled and translated versions of a wavelet basis function [3]. Since many wavelet bases such as Dauchebies4 or 6 have similar shapes to the transients, we expected good performance. Performance was better than the STFT, however, we were unable to find a wavelet basis that significantly improved the probability of detection compared to the energy detector. As well, the wavelet methods are not well suited to real-time processing because they operate on blocks of data, which adds an inherent delay to the detection. A related algorithm, called the adaptive optimum kernel method (AOK)[4] was also investigated because it is a real-time operation and it uses an adaptive kernel that tries to make a best fit to the signals. AOK is computationally very expensive and did not produce significantly improved results over the energy detector.

Matched filter processing involves convolution of the received data with a known signal, and detection of a peak arrival time. When the signal is long compared to the characteristic duration of the noise, this technique can detect wideband signals that are far below the noise. However, for short signals, and in cases where the signal shape correlates well with the noise, there is very little performance improvement compared with the energy detector. Small arms fire events fall into this category.

The conclusion of our analysis was that the energy detector is the most robust, and most effective detector. Because the ground wave is significantly different from the other signals, we are using a two-band detector. One band operates in the ground wave frequencies, the other operates across the full band. The energy detector compares the energy within a short time window to an estimate of the background energy. In estimating the background, it is important to minimize the effects of very high energy signals and to exclude frequency bands that contain more environmental and man-made noise sources than signal.

5. Experiments

The algorithms developed by MDA and DREV have been tested on a database of 10,000+ gun-fire events. There are a large number of false alarms, environmental conditions, and geometries in the database. The data was collected at three locations in CFB ValCartier, and one location near Halifax, NS. Figure 6 shows one of the locations at CFB ValCartier. Overlaid on the figure are results from a Guardian test and evaluation trial conducted by DREV. The vectors on the figure are localizations of shots by Guardian. During the trial Guardian had a very high probability of detection, and localized events within +/-3 degrees. Errors encountered were due to detection of target hits, and to cases where the shock and acoustic waves arrived simultaneously.

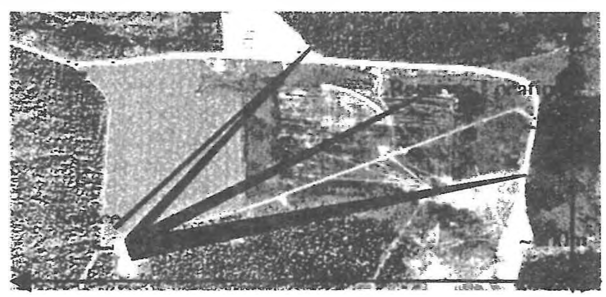

Figure 6: DREV Test Range, with Guardian Results.

6. References

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[3] See, for example, del Marco, Stephen, and Wiess, John. *Improved Transient Signal Detection Using a Wavepacket-Based Detector with an Extended Translation-Invariant Wavelet Transform.* IEEE Transactions on Signal Processing, Vol 45, No. 4, April 1997.

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