SIGNAL PROCESSING IMPROVEMENTS FOR INFRARED MISSILE WARNING SENSORS

Tamar Peli Atlantic Aerospace Electronics Corporation 470 Totten Pond Road Waltham, MA 02154

Myron Pauli Atlantic Aerospace Electronics Corporation 470 Totten Pond Road Waltham, MA 02154 Peter Monsen Atlantic Aerospace Electronics Corporation 470 Totten Pond Road Waltham, MA 02154

Kevin McCamey USAF WL/AAJ 2241 Avionics Circle - Suite16 Wright Patterson AFB, OH 45433 Robert Stahl Atlantic Aerospace Electronics Corporation 470 Totten Pond Road Waltham, MA 02154

Abstract

Dual-band Infrared-based passive Missile Warning Sensors (MWS) are under development at USAF Wright Laboratory and other DoD labs to provide aircraft with cost-effective robust detection and tracking of Infrared Surface-to-Air Missile threats out to their maximum launch ranges. Typically, such sensors are limited by the presence of heavy background clutter, solar glints, and sensor noise which lower the likelihood of missile detection. The heavy background clutter may also cause non-missile objects such as flares, glints, and smokestacks to be improperly declared as missiles. The longer detection range of missiles by these sensors is also limited by sensor noise; most noticeably in tropical weather conditions. Atlantic Aerospace and USAF Wright Laboratory have demonstrated two robust algorithms: a Geometric Whitening Filter which enhances the signal-to-clutter ratio and a Morphological Track Before Detect algorithm which enhances the signal-tonoise ratio. Use of these two algorithms in tandem will extend current Advanced Developmental MWS prototype sensors to detect Infrared-guided Surface-to-Air Missiles in heavy urban clutter and tropical maritime weather conditions.

Introduction

Missile Warning Sensors (MWS) serve as the front end for missile countermeasures whose purpose is to reduce the susceptibility of aircraft. As is true with any threat detection system, it is generally best to detect the threats at the earliest possible time (typically at missile launch) and also useful to track threat properties (such as angular location and amplitude) as they evolve in time. It is desirable that the MWS be capable of detecting and handing-over threats out near their maximum launch range. Additionally, since there is a possibility of multiple threats, it is also important for the MWS to be able to track missiles from ignition until motor burnout (and beyond). For a typical 2 stage Manpad (shoulder-launched Surface-to-Air missile), this capability is very stressed at the booster-to-sustain transition where there is as much as a 70% reduction in the missile signature at relatively long ranges.

The dual requirements of (1) early booster detection and (2) continuous tracking of missiles through the boost-sustain transition stress many Missile Warning Sensors (MWS). An InfraRed (IR) MWS requires a good signal-to-clutter ratio, hence, requires operating in an optimized spectral band for detection of the missiles against complex solar and thermal backgrounds arising from both man-made and natural sources. Detection of missiles within the optimal (primary) detection band is limited in range by both $1/R^2$ and atmospheric transmission. It is highly desirable for the MWS to be able to have sufficient Signal-to-Noise (S/N) ratio to detect booster ignitions out to the maximum launch range of EO/IR-guided SAM's, even in hot, humid weather. Additionally, the missile may go undetected in both boost and sustain phases until near motor burnout, thus forcing all countermeasures to be performed at short range and with very stressful timelines. Other missiles that may be picked up at boosters will get lost in noise as they turn into (dimmer) sustainer motors and will not be "re-detected" until they are nearly at sustainer burnout. The missile detection S/N ratio can be increased by a combination of hardware sensor improvements as well as by using signal processing improvements.

1052

CH36015-97/0000-1052 \$1.00©1997 IEEE

In addition to the problem of detection in "noise", there is a significant reduction in the performance of IR-based MWS fielded to date due to infrared background clutter. This clutter includes such things as: smokestacks, hot buildings, solar glints, and ordnance (fires, flares, etc.). Clutter causes three major problems: (1) it masks the actual missile signature such that the missile is too weak compared to the background clutter to be effectively detected, (2) it causes a large number of false tracks which both increases processing requirements and raises the detection threshold level required for target detection, (3) it gives rise to an unacceptable number of false missile declarations.

The Department of Defense has developed a plan to evolve to staring multicolor IR MWS as a response to the quality improvement and numerical proliferation of threat missiles. Even for a staring IR MWS, however: robust signal processing algorithms are required to best realize the potential performance against evolving missile threats in the 21st Century. This paper examines the use of Atlantic Aerospace's Detection in Clutter Enhancement (DICE) and Morphological Track Before Detection (TBD) algorithms for the MWS application as validated in several programs, primarily with USAF Wright Employment of the Detection in Laboratories¹. Clutter Enhancement algorithm enables one to use morphological techniques for spectral subtraction to achieve significant reduction in the residual clutter and get up to two orders of magnitude of false detection (exceedance) reduction for the same probability of detection. Application of the Morphological Track Before Detection techniques can enhance the effective signal-to-noise ratio and result in Manpad detection out to maximum range without a significant increase in false track formation. These algorithms are being sized for implementation into real-time signal processing for advanced MWS. Additionally, these algorithms may offer a cheaper solution to enhancing MWS detection range than other hardware approaches such as using larger optics with larger format focal plane arrays with greater dynamic range and/or faster focal plane array readouts.

Rationale for Spectral Clutter Subtraction

Shoulder-launched Surface to Air Missiles (SAM's) are, by definition, small since they are portable and can be launched by one or two individuals. Consequently, their signatures are also relatively small. In order to be detected by an infrared sensor against clutter backgrounds, the MWS

designer attempts to maximize the Signal-to-Clutter ratio (S/C). This is done first in hardware by (1) choosing a primary spectral band with the highest S/C for reasonable signal-to-noise (S/N) level and (2) having sufficient spatial resolution (Instantaneous Field of Regard) of the individual sensor pixels sufficient to get an adequate Probability of Detection (P_{A}) in heavy clutter. Trying to "brute force" the latter by going from 128x128 focal plane arrays to 512x512 focal plane arrays involves 16 times the amount of signal processing and may result in 16 times as many false detections and also 16 times the amount of false clutter tracks. Once a primary spectral band has been chosen for missile detection, it is important to optimize detection algorithms as well as selecting good quality focal plane arrays for the staring MWS.

Thermal clutter can dominate detection in a staring IR sensor unless good algorithms are employed. Differences between heated buildings and cold backgrounds can be quite noticeable - hence missiles may be indistinguishable from clutter patches, as illustrated in Figure 1. Thermal clutter variants may be the equivalent of several degrees K, even over a large area in urban/industrial scenes (such as a factor complex near cold/frozen water). Solar reflections between dark and bright clutter can be as significant as thermal clutter in the infrared. Choosing a good spectral (primary) band can achieve about an order of magnitude improvement in S/C, nevertheless, one is still often in a clutter dominated situation.

Traditional methods of clutter filtering that do not explicitly employ clutter are rather limited. Spatial Filtering involves removing a spatially "local" mean from the background clutter. As illustrated by the drawing in Figure 1, if the "local" (e.g., neighboring) clutter differences are large compared to the strength of a SAM's infrared signature, then any type of spatial filtering will be inherently limited by the sensor IFOV and the clutter. One can "brute force" a solution with spatial filtering by getting the IFOV of a MWS down by, for example, a factor of 10 - but at the cost of 100 times the signal processing, larger optics, larger focal plane arrays, and potentially as much as 100 times the leakage of residual clutter tracks into a post-detection Temporal filtering (or spatio-"track" processor. temporal filtering) is potentially powerful to pick up rapid changes in background clutter. Temporal filtering itself is often spoiled by such objects as solar glints and aircraft motion (which causes "bright" clutter to acquire some residual motion). Methods that attempt to remove the motion of the aircraft in

order to examine temporal differences are computationally intensive. These temporal difference techniques are also highly susceptible to glints and they are only proven to identify missile launches and not to detect and track missiles when they are in nearly-steady burning phase.

Most embodiments of single-band signal processing apply the classical methods of spatial, temporal, and spatio-temporal processing to the sensor imagery that results in a single band filtered (residual) image. This image is typically thresholded with a Constant False Alarm Rate (CFAR) threshold which requires that "target-like" objects be brighter than some multiple of the standard deviation of the residual clutter/noise. The standard deviation (σ) may be defined from the mean absolute value or the rootmean-square deviation; it may be computed locally or globally. The pixel locations that pass through this CFAR thresholding are commonly called exceedances and can be sent through some further tests prior to track establishment. Tracks may then be established on true targets of interest, target-like objects (for example, one could track an afterburning airplane while actually "looking for" missiles), and on the background clutter. This process would be adequate except for the fact that targets are often very "weak" compared to the background clutter - thus, the tracker may be flooded with false exceedances/tracks while the true targets may be too weak in amplitude to pass the CFAR threshold.

The simplest implementation of dual or multiple band signal processing preserves the single-band filtering approach (spatial, etc.) up through the CFAR thresholding process. After thresholding, one may track the amplitudes in several spectral bands and then ratio these amplitudes in order to properly identify missiles from solar glints, etc. However, this approach does not increase the probability of detection for a weak target buried in clutter. It is desirable to suppress clutter in a way that significantly reduces the clutter background standard deviation.

The use of spectral filtering to reduce clutter standard deviation in a CFAR-limited target detection system is illustrated with Figure 1. The top data curve in Figure 1 shows a target "buried" in a background consisting of thermal emission, diffuse solar scattering, and a direct solar glint. This would be representative of a one-dimensional slice of imagery from a sensor operating in the "primary" band. The primary band is chosen such that the target's signal to clutter ratio is large, relative to that of other spectral bands. The second curve in Figure 1 shows an example one-dimensional slice of imagery in the "reference" band, chosen such that the clutter is similar to that in the primary band, but with a much smaller relative contribution from the target. The purpose of a spectral clutter rejection filter is to find an effective means of removing the clutter in the primary band by using the reference band data^{1,2,3,4}. The output is the "whitened" residual image as shown in the bottom curve of Figure 1. As one can see, two desirable effects can occur with spectral filtering:

• the clutter standard deviation σ is significantly reduced, hence weak targets will now exceed the CFAR based threshold (e.g., Signal >>"whitened" σ). • point-like objects such as solar glints whose spectral properties do not resemble targets will actually be *negative* and thus not be passed into the track processing.

It is worth noting that the spectral clutter reduction works best on the high value tail of the clutter distribution which is exactly the type of clutter which causes the most missed detections and false tracks.

Geometric Whitening Filter For Removing Clutter

A common implementation of spectral clutter filtering uses a *linear* dual-band approach^{2,3,4}. The linear dual-band algorithm models clutter in a given IR band by an optimal linear estimate based upon a second IR band (optimal in the sense of minimum residual power). Computations are done locally, using a sliding window, which allows some adaptation to non-homogeneous background statistics. The essence of linear adaptive crossmodeling is that the image in one spectral band is estimated (modeled) by linearly scaling the image in a reference spectral band. Letting i,j denote sensor pixel space, the whitened image can be written as:

(1) $W_{i,j} = R_{i,j} - [\{ < R * B > / < B * B > \}_{local} * B_{i,j}]$

where the primary ("red" image R $_{i,j}$) and reference band ("blue" image B $_{i,j}$) have been locally demeaned and/or spatially filtered prior to the spectral subtraction. The linear dual-band whitening filters have been successfully used in missile warning applications¹ and in surveillance applications², however its performance gain is highly dependent on level of correlation across the two bands (typically > 0.9). By choosing a primary plume detection band of longer wavelength ("red") than the reference band, hot objects such as solar glints. The requirement for high level of clutter correlation as well as the computational complexity of the linear dual band process motivated the development of the *dual band* Geometric Whitening Filter developed by Atlantic Aerospace Electronics Corporation and validated under the USAF Wright Laboratories Detection in Clutter Enhancement (DICE) program.

The dual-band Geometric Whitening Filter (GWF) is based upon a class of adaptive, nonlinear, morphological signal processing techniques. It has been successfully demonstrated on both scanning and staring sensor imagery under the USAF Wright Laboratories Detection In Clutter Enhancement (DICE) program. The GWF has the following advantages over the linear dual-band clutter subtraction:

• the GWF uses less and simpler signal processing operations per pixel than the linear approach - the GWF uses 150 basic operations (add, subtract, minimum, maximum and shift) and one multiplication (equal to up to 16 basic operations) per pixel, thus requiring cheaper signal processing hardware than the linear dual-band algorithm.

• the GWF works better than the linear algorithm in cases where optical blur causes point-like targets to extend into more than one sensor pixel.

• the GWF works better than the linear algorithm does when the clutter correlation between the primary and reference band is low or when the clutter to noise ratio in the two bands is low.

• the GWF works better than the linear algorithm at clutter interfaces such as earth-sky or cloud-ground backgrounds, because large windows for reliable statistics are not required.

• the GWF degrades more slowly than the linear approach as a function of sensor/clutter misalignment and target coloration.

• the GWF is less sensitive than the linear approach to clutter and sensor anomaly such as saturated pixels, "blinking" pixels, etc.

The basic GWF algorithms (as it has been applied for imagery from 2-dimensional staring focal plane array imagery) are shown in Figure 2. The GWF consists of a series of grayscale morphological operations (erosion, dilation, opening, and closing) which operate on both the primary and reference band imagery. These morphological operations essentially use comparisons of neighboring pixels in imagery to expand in size (or to contract) local features within the image. Using the proper combination of morphological operations effectively correlates the primary and reference band imagery on a pixel-bypixel basis in order to obtain a highly accurate estimate of the background clutter image (the image without the true targets) which is used to derive the residual ("white") image.

Geometric Whitening Filter Performance Evaluation

Algorithm performance was measured in terms of Receiver Operating Characteristic (ROC) curves, which show target Probability of Detection (P_d) vs. false exceedance probability on a per pixel single frame basis. Performance was assessed on both two-dimensional staring focal-plane-array and scanning data^{1.5}. Example ROC curves for the GWF are shown in Figure 3 for a scanning sensor and in Figure 4 for a staring MWS. The staring data also came with range information which was further used to evaluate range performance for MWS applications⁵. Spectral correlation of the scanning MWS clutter was as low as 0.7 since that scene is far more noise dominate while staring MWS clutter correlations were often higher than 0.95 in the heaviest part of the clutter tail.

The GWF technique performed significantly better than single band spatial filtering on all clutter images analyzed under the DICE program. In heavy clutter, the GWF technique was able to obtain: (1) a 100-fold reduction in false exceedance rates for a given target range or (2) a 45% increase in target detection range for a given false exceedance rate with one-tenth the number of residual clutter tracks forming. As expected, the GWF considerably out-performed the linear color subtraction on the low C/N scanning data (about a factor of 2 reduction in target S/C was found compared to the linear subtraction technique). In the higher correlated staring data, GWF still performed as well or better than the linear dual-band subtraction with performance differences growing in significance as sensor misregistration grew, target coloration (spectral ratio of primary/reference for missile compared with primary/reference for background) decreased, and for targets blurred out over four-pixels. Not surprisingly, for highly correlated scenes with one-pixel targets and a high degree of target correlation, the GWF and linear techniques converged. The performance advantages of the GWF over the linear techniques are due to the fact that dualband IR sensors typically suffer from noise, sensor anomalies, and misalignment and that targets have limited coloration and can be blurred over multiple pixels. The other added advantage of the GWF comes as it is simpler to implement in high speed parallel image processing architectures. This is due to the morphological nature of the GWF technique which requires only 150 basic operations and 1 multiply per pixel.

Using Track Before Detect To Enhance Weak Target Detection

The overlap of signal processing and tracking functionality occurs when a sequence of sensor scans (frames) is processed prior to thresholding. This approach allows increased processing gain to be achieved by using information that might otherwise have been discarded by premature thresholding of the data in individual scans. In order to derive processing gain from a time-sequence of images, it is necessary to follow the trajectory of a target as it moves in the data space from each scan to the next. This corresponds to a (simple) tracking operation, thereby resulting in overlap of processor functionality. The generic class of algorithms in which thresholding is deferred until a time-sequence of image scans has been processed, is called Track-Before-Detect (TBD). Since target trajectories are not known prior to detection, TBD schemes typically require that multiple frame (scan-to-scan) processing be performed against multiple, simultaneous target trajectory hypotheses⁶. Detections are declared for those hypotheses for which the integrated energy exceeds appropriate threshold levels.

After the application of Geometric Whitening Filtering, the residual clutter image is largely dominated by temporal and spatial (residual nonuniformity) noise. In hot humid weather, the optical transmission out to the maximum launch range of SAM's may be << 1 - thus, one will naturally be left with a noisy (non-clutter dominated) scene for long range SAM detection. Air-to-air missiles are typically against relatively low level cloud clutter or blue sky and are also generally dominated by sensor noise after spectral clutter subtraction. Since the residual signal irradiance at the sensor goes as exp $(-aR)/R^2$ and this irradiance must be greater than some multiple of the local CFAR standard deviation (σ) , the detection of weak targets will be controlled by the standard deviation of the noise. The sustainer phase of a two stage missile motor is often much weaker than the bright initial boost phase; yet it must be tracked at nearly the maximum of the missile's launch range. These boost-to-sustainer transitions cause the greatest stress on sensor noise requirements to date. The Track Before Detect (TBD) algorithm represents a robust method of enhancing detection of very faint objects by correctly integrating target energy in multiple frames versus the incoherent temporal noise background. The TBD techniques can also be preferentially weighted (biased) to prefer target-like objects over clutter-like objects and to prefer target/clutter over static sensor pixel anomalies from uncompensated spatial non-uniformities in the IR focal planes.

Morphological-Based Track Before Detect Algorithm

Under a USAF-sponsored Small Business Innovative Research Program, Atlantic Aerospace has been developing an integrated geometry-based TBD process that offers an alternative solution. The TBD algorithms take advantage of the statistical *dependence* (correlation) of target measures from multiple frames in order to increase signal strength relative to noise signals, which are statistically independent from The GWF approach eliminates frame to frame. correlated background features from a sequence of frames by "whitening" each scan through the use of effective geometry-based (spatial-only, an or combined spatial-spectral pre-processing) prior to TBD processing. The baseline TBD process is a nonlinear energy maximization procedure that does not require parallel processing for multiple trajectory hypotheses.

The geometry-based TBD process is based on a class of non-linear signal processing algorithms developed by Atlantic Aerospace, and which eliminates computationally expensive multiplehypothesis processing by deriving "maximum energy paths" directly from the three-dimensional image sequence data. These paths correspond to target tracks within the sequence of GWF "whitened" Traditionally the number of integrated imagery. frames has an impact on performance; additional frames provide an increase in S/σ . For missile warning applications, the number of integrated frames is bounded by the required threat declaration range for missiles; however, in a 25 - 200 Hz staring sensor, this can be a relatively large number of frames. This is especially true if such a sensor is also employed against long range missiles (>10 Km.) or as an InfraRed Search and Track (IRST) sensor against long range aircraft.

The general flow of the overall Track-Before-Detect processing chain is depicted in Figure 5. The first stage is a single frame process whose objective is to whiten the input image. The second stage stacks a sequence of multiple whitened frames to construct a 3D volume for track extraction. The frames can be directly stacked or can be approximately aligned (but not at the sub-pixel level) based on sensing geometry and frame-to-frame platform/sensor motion. The third stage performs the extraction of tracks using a geometric optimality criterion. Since the third stage of the process does not assume any strict dynamic models for the target, the extraction of target tracks should be done on a temporal slice of scans as depicted in Figure 6 and the output transferred to a classical tracker. In order to ensure path continuity, the temporal slices should overlap typically by 25% to 50%. Each of the extracted path components can be used for either track initiation or track update. For bright missile launches as close range, single frame detection can be used with a very high threshold setting.

An example of the use of the TBD algorithm is shown in Table 1 and Figure 7 for faint beam-rider missiles inserted in heavy urban background clutter data from the staring focal-plane-array sensor. Beamrider missiles employ guidance schemes such that their apparent position appears "fixed" compared to the background clutter - hence other temporal means of clutter rejection will not work on these targets differencing reduces signal-to-noise and velocity based "optical flow" and similar techniques reject targets that stay apparently fixed with the clutter. The TBD algorithm was applied over a 0.4 second integration on the staring MWS data as was a series of "optimized" Multiple Track Velocity Hypotheses (henceforth called MTVH). The MTVH algorithm chose the optimal 3-dimensional (spatio-temporal) path from 49 different target velocity hypotheses. As the number of velocity filters used increases, the false alarms from the MTVH also increases. However, this was not the case with the Morphological TBD algorithm which does not require making specific hypotheses about target velocity. As shown in Table 1 and Figure 7, the Morphological TBD approach outperformed the MTVH approach as well as the single frame GWF processing.

The robust and computationally simple TBD approach can reduce the sensor residual noise by a factor of 3 or more. The difference in atmospheric propagation in going from a moderate temperature dry climate to a tropical maritime climate is a factor of 3 in propagation at the maximum boost-to-sustain transition range for SAM threats. Hence, a 10 frame summation using the TBD approach is able to recover the "good" weather performance specifications of the MWS which is typically designed to get a good probability of continuous tracking of a burning missile from launch - even for launches out to the SAM's kinematic limit. The TBD techniques can easily be extended for using a MWS as a longer ranged IRST (Infrared Search and Track) sensor where there are generally several seconds allowed before one must declare a track.

Conclusions

The Geometric Whitening Filter and the Morphological Track Before Detect provide a robust set of algorithms to serve as a front end baseline for reducing clutter and noise, respectively, present in Missile Warning Sensors. Unlike many other clutter and noise reduction techniques, these two algorithms operate with a minimal amount of assumptions about threat missiles, are easily suited for all current and projected dual-band MWS systems, and can be performed by state-of-the-art real-time digital signal processors at low cost. They serve to reduce the cost and risk of missile warning by using algorithmic techniques rather than brute force methods (more pixels, bigger optics, more computational power) to reduce clutter and noise. This work is suitable for adaptation to advanced avionics systems requiring missile warning.

References

[1] K. McCamey, R. Marko, L. Garvin, and T. Peli, "Detection in Clutter Enhancement", SPIE volume 2742 p. 225.

[2] M. Pauli, G. Katz, D. Fraedrich, J. Inderhees, and D. Nordmeyer, "Dual Waveband Electro-Optical Signal Processor", U.S. Patent 5,371,542, awarded December 6, 1994.

[3] G. Katz, M. Pauli, D. Fraedrich, and M. Satyshur, "Applicability of Spectral Filtering to Missile Detection Using Staring Sensors at MWIR Wavelengths", proceedings of the IRIS Conference on Targets, Backgrounds, and Discrimination, 1987.

[4] L. Stotts, E. Winter, and I. Reed, "Clutter Rejection Using Multispectral Processing", SPIE volume 1305 (Conference on Optical Engineering and Photonics in Aerospace Sensing - April 1990).

[5] K. Sarkady et al, "Missile Signature and Urban Clutter Measurements from a Two Color MWIR Missile Approach Warning Sensor", proceedings of the IRIS Symposium on Targets, Backgrounds, and Discrimination, January 1995.

[6] I. Reed, R. Gagliardi and L. Stotts, "A Recursive Moving-Target Indication Algorithm for Optical Image Sequences," *IEEE Transactions on Aerospace* and Electronic Systems, May 1990.

Author Biographies

Ms. Tamar Peli is Vice President of Atlantic Aerospace and Director of the Image Exploitation Group of Atlantic Aerospace Electronics Corporation. She has been at Atlantic Aerospace since 1988 working as a Principal Investigator on several problems including missile warning, infrared search and track, automatic target recognition, acoustic detection, and wavelet applications. Prior to that, she worked as a member of the technical staff at MIT Lincoln Laboratory from 1979-1988. She holds an MS and BS in Electrical Engineering from Israel Institute of Technology and is the author of 17 papers in image processing techniques. Mr. Peter Monsen has served as a principal investigator of morphological track-before-detect algorithms at Atlantic Aerospace. He has worked at Atlantic Aerospace since 1993 on whitening filters and SAR/IR sensor fusion. Prior to that, he worked at Charles Stark Draper Laboratory and at MIT Lincoln Laboratory. He holds an Engineering Degree from Northeastern University, a MSEE from Pennsylvania State University, and a BSEE from Worcester Polytechnic Institute. Mr. Robert Stahl has been at Atlantic Aerospace since 1996 working in infrared signal processing. Prior to Atlantic Aerospace, he worked at Naval Undersea Warfare Center from 1984-1996 on advanced sonar systems and real-time signal processing. He holds a MSEE from the University of Connecticut and a BSEE from SUNY at Buffalo. Dr. Myron Pauli has been a Senior Scientist at Atlantic Aerospace Electronics Corporation since 1995. He has been working in the fields of missile warning sensor and algorithms, proximity fuze technology, and infrared countermeasures systems analysis. Prior to that, he was at the U.S. Naval Research Laboratory's Optical Sciences Division from 1985-1995. He obtained a PhD in nuclear physics from MIT and a BS in Physics from Case Western Reserve University in 1973. He is the author of over 50 publications in infrared signal processing, missile warning, and in nuclear physics. Mr. Kevin McCamey is the branch chief for threat detection at the USAF Wright Laboratory's Electro-Optical Division where he has worked on warning both missile and laser infrared countermeasures technology. He has been at Wright Laboratories since 1985. He has an MBA, MSEE, and BSEE, all from the University of Dayton.

TABLE 1 : Comparison of Detection Probability (P_d) vs. False Detection Rate $(P_{fa} - given in false detections per image per 10,000 pixels) on a low signature beam-rider target inserted into urban staring sensor clutter data for 10 frame MTBD vs. Single Frame (SF).$



Figure 1: Example of correlated spectral subtraction on thermal clutter with missile and alint embedded



Figure 2 : Non-Linear Dual Band GWF Algorithm Overview



Figure 3: Comparison of signal processing performance of single band, dual-band linear, and dual-band (Non-Linear) Geometric (GWF) whitening filters on multi-band scanning sensor data for inserted targets of various strength given in units of sensor Noise Equivalent Irradiance (NEI). P_d = Probability of Detection for a given target strength, P_{fa} = Rate of false detections/pixel/image. Solid and dashed lines refer to the amount of target coloration R between primary and reference bands. Note: GWF can detect 4 NEI targets (vs. 8 NEI for other methods).



Figure 4 : Comparison of signal processing techniques on staring MWS data [from reference 5]. Targets of relative strength 1.0, 0.3, and 0.1 were inserted into sensor imagery for detection probability P_d vs. # of false detections / image / pixel (P_{fa}) at 4 Km (left side) and 6 Km. (right side) detection range. Top curves - non-linear GWF ; middle curves - linear 2-color filter ; bottom curves - single band detection. R = target coloration ratio.

1061



Figure 6.

ALL CONTRACTOR

Temporal Slicing for the Geometry-Based Tack-Before-Detect Process



Figure 7: Performance Comparison between the MTVH algorithm (with 49 velocity filters) and the Geometry-based TBD for 10 frames of integration against staring MWS Baltimore4 Scene, Beam Rider Target, at range bins of 3-4 Km, 4-5 Km and 5-6 Km. The Morphological TBD is the solid lines.



Figure 7: Performance Comparison between the MTVH algorithm (with 49 velocity filters) and the Geometry-based TBD for 10 frames of integration against staring MWS Baltimore4 Scene, Beam Rider Target, at range bins of 3-4 Km, 4-5 Km and 5-6 Km. The Morphological TBD is the solid lines.