3RD GENERATION THERMAL IMAGER SENSOR PERFORMANCE

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1. OVERVIEW

3rd Generation FLIR (3rd Gen) is defined as a dual band (MWIR and LWIR) thermal imager. It is targeted to be one of the principle sensor systems for the Army's Future Combat System (FCS), Stryker, and Airborne Reconnaissance System. In early 2005, the Night Vision and Electronic Sensors Directorate (NVESD) created a large scale project to research and quantify the potential benefits of a 3rd Gen FLIR.

This research was partitioned up into multiple individual studies, each of which is focused on a particular technical area, i.e., topic, to quantify its impact on the performance of a 3rd Gen FLIR. The set of topics include long range target identification (ID), aided target recognition (AiTR), apparent high temperature (T) sources of clutter, target and background contrasts and signatures, conventional and urban search and detection, advanced signal processing, cold weather, atmospheric turbulence, sensor integration time, camouflage, spectral signature differences, smoke, pilotage, wet targets, laser susceptibility, and path radiance. Whenever possible and appropriate, actual MWIR and LWIR imagery were used as inputs in the applicable physics (or psycho-physics) models. Even though every attempt was made to partition a research project of this size and scope into individual, independent components of an n-dimensional parameter space, it was obvious that there were varying degrees of dependence amongst and between these topics.

In each of these studies, specific benefit of 3rd Gen FLIR was assessed from either the direct or indirect impact upon target discrimination task performance. Examples: in the search and detection study, actual wide field of view (WFOV) imagery was used to directly measure target task performance of trained military observers performing laboratory perception tests; in the phenomenology studies, benefit of 3rd Gen was assessed by the magnitude and distribution of MWIR and LWIR thermal signatures with the assumption that task performance was proportional to signature; and in studies involving sensor properties or sensor properties plus phenomenology, benefit of 3rd Gen was assessed by task performance modeling with the physics-based NVESD thermal imager model NVThermIP and the USAF atmosphere model MODTRAN.

A majority of the 21 individual research studies has been completed at the time of this writing. Because of limited space, this paper provides only a very brief description of each of those topics that have been completed and corresponding results along with the type of sensor that provides superior performance. Even though this overall research is not yet complete, the results strongly indicate that a 3rd Gen FLIR concept provides a significant operational performance advantage over single band thermal imagers alone.

2. INTRODUCTION

3rd Gen FLIR is defined as a large format staring array that can image in two bands: one in the MWIR (3 to 5 μm) and one in the LWIR (8 to 12 μm). It may also include filters to tune the system to one or more sub-bands in the MWIR and the LWIR. However, the dual-band (MWIR and LWIR) focal plane is a cornerstone of 3rd Gen FLIR and a great deal of progress has been made in producing it. It may also be dual F-Number (a low F-number mode for WFOV search and detection and a higher F-number mode for narrow field of view (NFOV) target ID).

As mentioned above, many of these individual research investigations have been completed over the past year. The overall research is expected to be completely finished shortly after the end of CY 2006, but because significant progress has already been accomplished, a number of papers have been presented at technical, defense oriented symposiums in order to promulgate results rapidly to interested parties. It is expected that when this project is finished, much of this research will be reported in peer-reviewed literature. In the following section, we provide brief summaries of the research topics that have been completed and their results (or preliminary results) where available.

3. RESEARCH TOPIC SUMMARIES

The 1st topic was long range target identification (ID). The conventional wisdom used to be that the *minimum* benefit of 3rd Gen FLIR could be realized by performing WFOV search and detection with the LWIR band and long range ID with the MWIR. The goal here was to determine the success of this approach. NVESD performed an analysis using NVThermIP with real hot and cold target data and nine MODTRAN environments

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 NOV 2006	**N/A**	**-**

4. TITLE AND SUBTITLE
3RD Generation Thermal Imager Sensor Performance

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army RDECOM CERDEC NVESD 10221 Burbeck Rd Ft. Belvoir, VA 22060-5806

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002075., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

for 3rd and 2nd Gen FLIRs, and staring MWIR and LWIR sensors. The research provided two major findings for sensors using the same optics and focal plane geometries and integration times optimized for minimum noise: 1) in NFOV, MWIR provided significantly larger ID ranges than LWIR under most conditions; 2) in WFOV, MWIR detection ranges were similar to LWIR detection ranges under most conditions (see Figure 1). For long range ID, a high quality MWIR FLIR would provide superior performance over a LWIR FLIR and equal performance to a 3rd Gen FLIR.

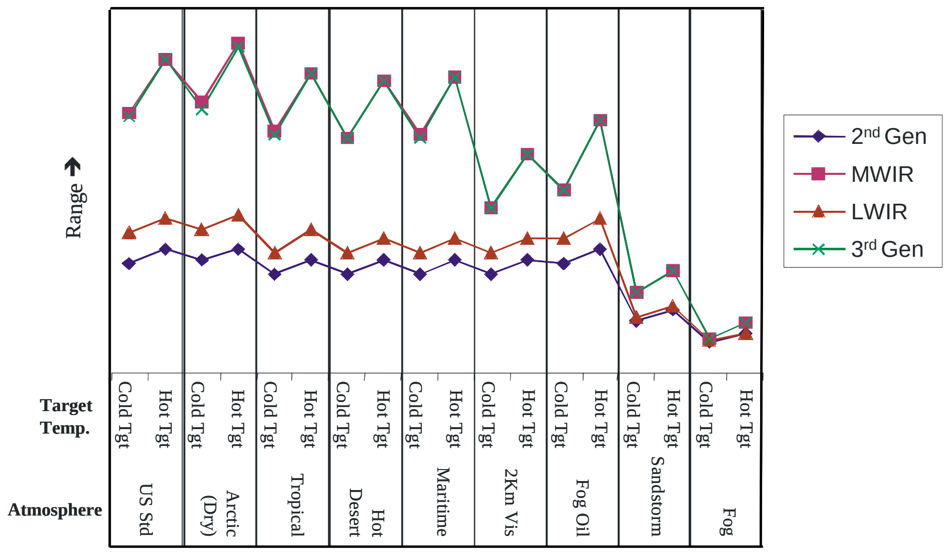


Figure 1. Long range target identification

Next was AiTR performance: MWIR day vs night. MWIR Aided Target Recognition (AiTR) performance suffers in the day compared to the night. This degradation is related to high levels of daytime clutter caused by solar reflections and loading and shadows. This level of degradation is not seen in the LWIR. In addition, nighttime AiTR performance in MWIR has been shown to be higher than in LWIR due to slightly higher resolution. The goal was to investigate AiTR performance of MWIR as a function of time of day. To that end, NVESD collected and processed day and night imagery in the MWIR for AiTR analysis. The results confirm the reduction in MWIR performance during daylight hours, and that daylight performance is a function of view angle and sun position (see Figure 2). These results indicate that a dual band AiTR, i.e., MWIR at night and LWIR in day, could provide a significant increase in overall system AiTR performance. Thus a 3rd Gen FLIR would provide superior performance to either a single band MWIR or LWIR alone.

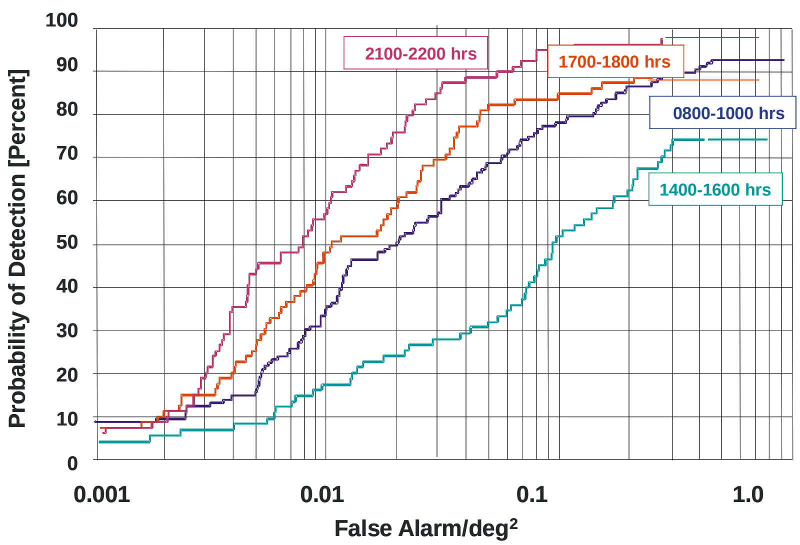


Figure 2. MWIR AiTR Performance as a Function of Time of Day

Next was AiTR performance: 2-Band vs 1-Band. It had been demonstrated in an earlier experimental multiband sensor program that 3-band (designated as LWIR1, LWIR2, and MWIR) AiTR performance is better than either 2-band or 1-band performance. The goal was to specifically investigate LWIR plus MWIR AiTR performance versus single band AiTR, either LWIR or MWIR. NVESD collaborated with Raytheon to combine the two LWIR bands into one and used the associated MWIR data to investigate 2-band and 1-band AiTR performance. In addition, NVESD just completed another investigation of 2-Band (MWIR plus LWIR) vs 1-band (MWIR and LWIR individually) AiTR response based upon a Signal-to-Clutter Ratio metric. The final results are currently being compiled, but they indicate that two bands work better than one, and so a 3rd Gen FLIR would provide superior performance over a single MWIR or LWIR band sensor.

Next was burning barrels, dynamic range, blooming, and veiling glare. Thermal IR image information is primarily carried by changes in apparent ΔT between image pixels. For high T sources (i.e., T > 469 K), the change in radiant flux for small ΔT is much larger in the MWIR than in the LWIR. This huge signature in the MWIR compromises the system dynamic range by taking up display levels and saturating large regions of the image. Not only are a compromised dynamic range and large area saturation major impacts, but blooming on the detector and veiling glare in the optics can result from such high source quantities. The goal here was to investigate the impact of large scene dynamic range in the MWIR and LWIR. NVESD collected imagery of burning barrels and other hot sources and measured the large area saturation. Results showed that hot sources compromise the MWIR much more so than LWIR, and so a LWIR FLIR would provide superior performance to a MWIR sensor and equal performance to a 3rd Gen.

Next was conventional target contrast. Visibility of target detail in an image is determined by their contrast relative to the rest of the image. The goal was to determine if target contrast favored the MWIR over the LWIR, where the target contrasts were computed using RSS ΔT:

$$\mathbf{RSS}\ \Delta\mathbf{T} = \sqrt{\left(\left\langle \mathbf{T}_{\mathbf{Target}} \right\rangle - \left\langle \mathbf{T}_{\mathbf{Background}} \right\rangle\right)^2 + \sigma^2_{\mathbf{Target}}} \qquad \mathbf{(1)}$$

(⟨⟩ indicates the average T and σ^2 is the variance in T). NVESD analyzed a large library of existing imagery of military vehicles, and when corresponding MWIR and LWIR contrasts were plotted against each other, the data showed that, on average, the MWIR target contrasts were approximately the same as the LWIR. However, these data also showed specific cases where MWIR contrasts dominated and others where the LWIR dominated (see Figure 3). This suggests that the availability of both bands in a 3rd Gen FLIR provides a significantly greater probability of at least one high contrast per target than with either MWIR or LWIR alone.

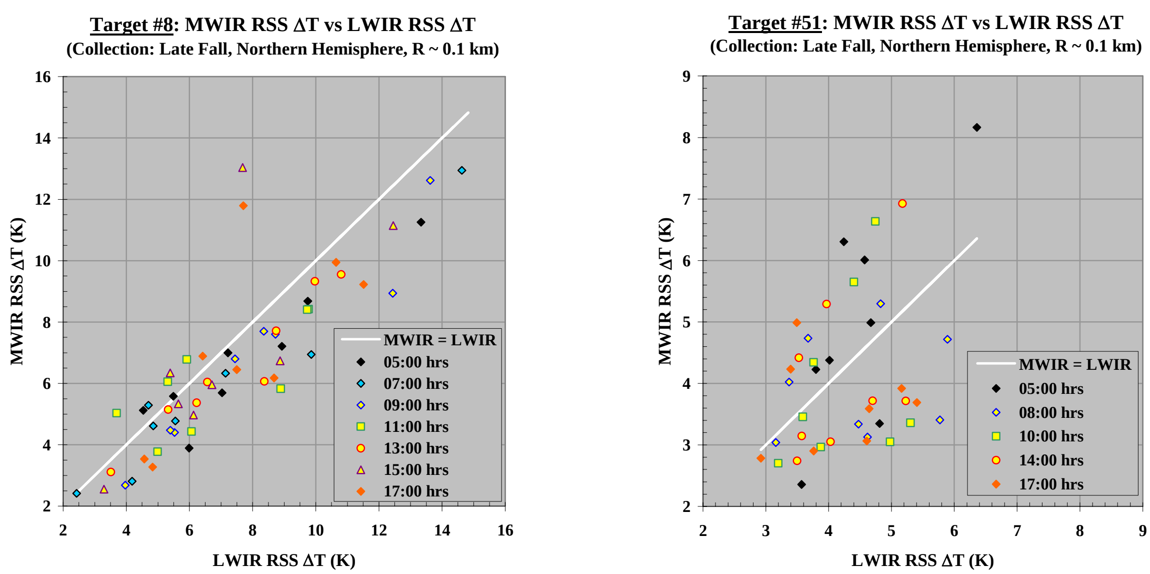
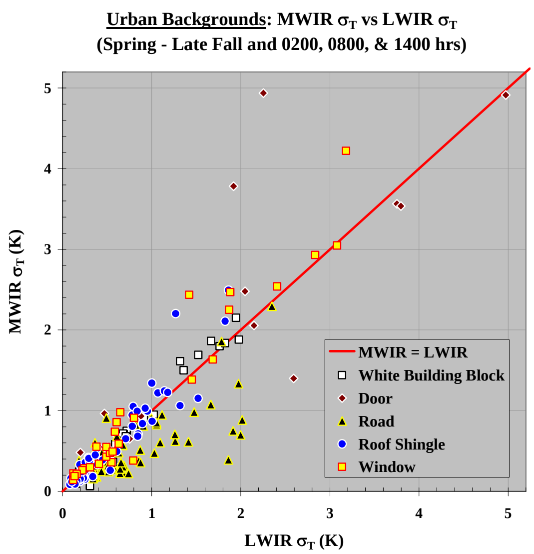


Figure 3. MWIR vs LWIR conventional target contrast

Next was human target contrast. The goal here was to determine if human target contrast favored the MWIR over the LWIR, and so the analysis that was performed for conventional targets was repeated for human targets. NVESD collected a large amount of "up close" human data for this analysis. The targets consisted of males and females in various uniforms and civilian dress, armed and unarmed, and at many aspect angles. The results showed that human contrast were slightly higher in the MWIR, but there were specific cases where MWIR contrasts dominated and others where the LWIR dominated**Error! Reference source not found.**. As with the conventional targets research, these results suggest that a 3rd Gen FLIR would provide a significantly higher probability of at least one high contrast per target than either MWIR or LWIR alone.

Next was conventional (rural) and urban background contrast. The goal was to determine if background contrast favored the MWIR over the LWIR, but backgrounds cannot be described with RSS ΔT; however, the MWIR and LWIR thermal contrasts, i.e., standard deviation of apparent T (σ_T), of a background area can be compared. NVESD collected a large variety of rural and urban background imagery from Spring through late Fall at various times of day. The results showed that on average, both the rural and urban backgrounds had about the same σ_T in the MWIR as in the LWIR. However, the results also showed specific cases where MWIR contrasts dominated and others where the LWIR dominated (see Figure 4). As with the conventional and human target contrast topics, these results suggest that a 3rd Gen FLIR would provide significantly higher performance than either MWIR or LWIR alone.



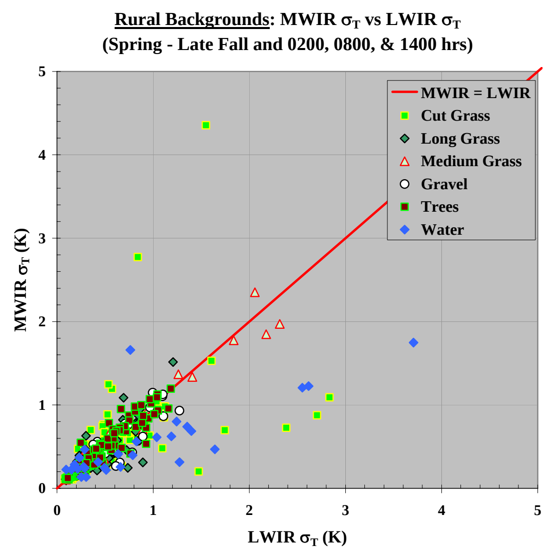


Figure 4. MWIR vs LWIR conventional and rural background contrast

Next was conventional search and detection, In WFOV search or detection, sensor resolution is limited by detector size and sample spacing, and in such a case there is no diffraction advantage for MWIR over LWIR. NVESD collected WFOV imagery and performed human perception experiments with conventional targets to learn if there was any advantage of MWIR over LWIR for search and detection as a function of time of day. The results showed that, on average, MWIR performed about the same as LWIR in probability of detection and search times. However, MWIR performed better at night and LWIR performed better in the day (see Figure 5). These results indicate that a 3rd Gen FLIR would provide superior performance than either LWIR or MWIR alone.

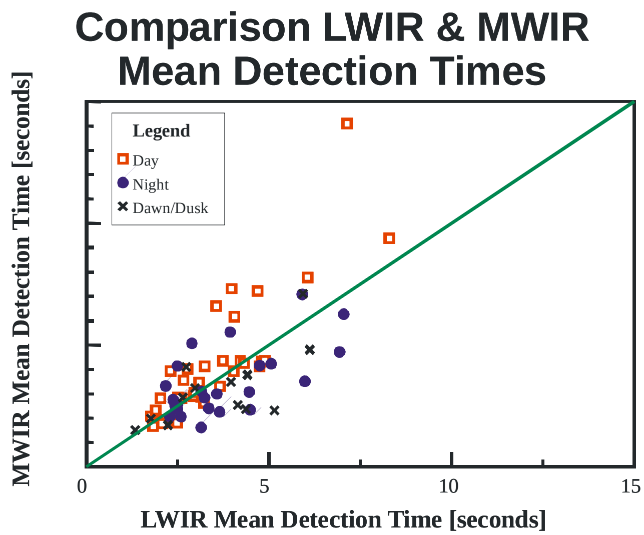
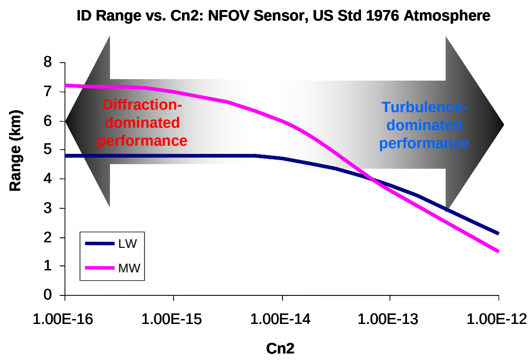


Figure 5. MWIR vs LWIR mean detection time for conventional targets in rural environment.

Next was advanced signal processing: LCE and boost. Advanced signal processing techniques such as localized contrast enhancement (LCE) and high frequency boost are currently used to increase the visibility of details in imagery. The goal here was to see if these techniques would benefit to LWIR over MWIR. NVThermIP was used to model these techniques for a long range scout sensor and a medium range sensor over various ranges in both bands. Results show that both MWIR and LWIR sensors see significant but similar increases in range performance for high F-number systems and high contrast targets. However, range performance benefits are minimal or even negative for low target contrast. The performance benefits were judged to be the same for both bands and thus 3rd Gen would not provide superior performance.

Next was cold weather performance. The MWIR is thought of as a photon-starved environment compared to LWIR. (At a T of 300 K the LWIR photon flux is about 46 times greater than MWIR.) However, this characteristic is only important when sufficient photons can not be collected within some reasonable fraction of a frame time or a period required to minimize motion blur in imagery. The goal was to use noise modeling and NVThermIP to model how MWIR and LWIR range performances were affected by cold scene T. The results show that MWIR performance does degrade with decreasing T whereas LWIR performance is not much affected[1], and thus LWIR was judged to provide superior performance over MWIR at low background T.

Next was turbulence, which occurs where a large ΔT between ground and air causes index of refraction fluctuations in the air. Its impact on image quality is a function of aperture diameter and wavelength, and so the goal here was to see if MWIR would perform better than LWIR in turbulence. NVESD modeled its impact on the performance of MWIR and LWIR sensors of equal aperture as a function of atmosphere type using MODTRAN and NVThermIP. The results showed that when turbulence reaches an atmosphere type-dependent threshold, the LWIR performance can actually exceed the performance in the MWIR (see Figure 6 for one atmosphere example)[2]. Distributions of global turbulence strength show that MWIR long-range ID performance would only occasionally be diffraction-limited (see Figure 6)[3]. Consequently, a 3rd Gen FLIR would provide superior performance over either MWIR or LWIR alone.



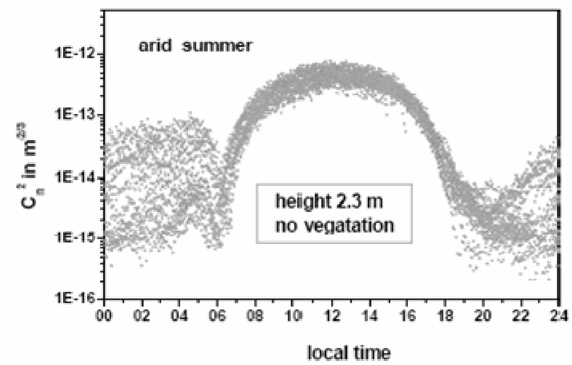
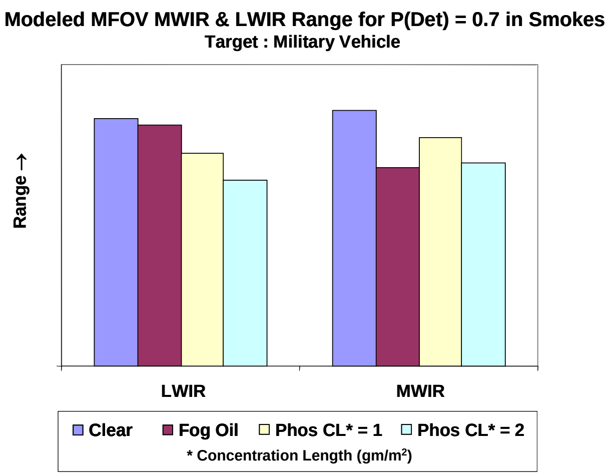


Figure 6. Example of modeled MWIR & LWIR range performance as a function of turbulence; and a characteristic day/night variation of C_n^2 in an arid/semi-arid climate[3]

Next was integration time. In IR imagery, a long sensor integration time translates into motion blur that can degrade performance. The goal here was to determine how sensor performance degraded as a function of integration time in the MWIR and LWIR. NVESD collected imagery of moving targets and stationary targets from a moving sensor for different integration times. Both the imagery and a simple analysis showed that target motion at reasonable ranges does not significantly degrade sensor performance in either band. However, when sensor motion is considered the MWIR results showed that performance is degraded with longer sensor integration times[4]. Because of the large photon flux in the LWIR, LWIR integration times had to be small to avoid image saturation, and thus performance was not affected. Since MWIR sensors require much longer integration times than the LWIR to collect the desired number of photons, there is a significant performance degradation in the MWIR. LWIR was therefore judged to provide superior performance to MWIR.

Next was smoke. Battlefield obscurants commonly occur in combat situations, and fog oil smoke from smoke generators is a common obscurant that is very effective in the visible band. The goal was to quantify the impact of smokes on MWIR and LWIR range performance. NVESD used existing models (NVTHERM IP with MODTRAN) to predict the performance of a MWIR sensor vs a LWIR sensor against fog oil and phosphorous smokes. The results showed that smoke does not eliminate the MWIR long range ID advantage due to diffraction, but there was a range advantage in the LWIR over MWIR for WFOV search and detection (see Figure 7). Therefore, a 3rd Gen system would provide superior performance over a MWIR or LWIR alone.



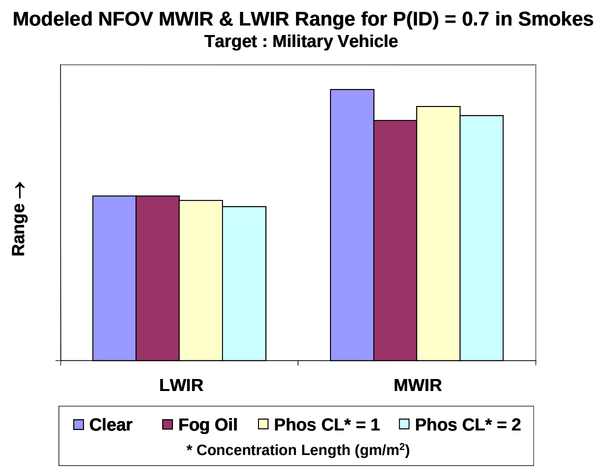


Figure 7. Modeled MWIR and LWIR range performance in smokes

Next was wet targets. Wet targets in wet backgrounds in the IR are challenging because they have low contrast and markedly different emissivity and reflectivity characteristics than when dry. The goal here was to investigate the impact of naturally occurring wetting, e.g., heavy rainfall, in the MWIR and LWIR, and so NVESD collected imagery of a variety of wet targets and backgrounds after a heavy rainfall. Preliminary results from the imagery show that in both the MWIR and LWIR, the apparent thermal contrast (σ_T) and dynamic range (ΔT) of target and background materials are significantly reduced when they are wet, and when they're wet, MWIR and LWIR σ_T and ΔT are almost identical. This indicates that the IR properties of water appear to dominate the scene. Some additional field measurements and sensor performance modeling remain to be completed before final conclusions are reached, but these preliminary results seem to indicate that performance would be the same in LWIR and MWIR.

The last of the completed research topics was path radiance. Atmospheric path radiance occurs in both the MWIR and LWIR as a consequence of thermal radiation and scattering by the atmosphere, and it can reduce the apparent image contrast of targets at long range. For ground based imaging sensors this effect occurs primarily in WFOV imagery where high path radiance may mask distant targets. This contrast reduction is less likely to occur in NFOV because the target and background will be at about the same range and have the same path radiance, which can be subtracted with sensor gain and level adjustment. The goal here was to determine how path radiance impacts MWIR and LWIR in the WFOV. Using MODTRAN atmospheric modeling data provided by the Army Research Laboratory, an analysis by NVESD shows that the impact on long range detection will depend upon the atmospheric conditions. The results are currently being finalized, but they show those conditions sometimes favor the MWIR and sometimes the LWIR. This indicates that a 3rd Gen FLIR capability would provide superior performance over a MWIR or LWIR alone

4. DISCUSSION AND CONCLUSIONS

The preceding section show that research into the potential benefits of 3rd Gen FLIR compared to a single band MWIR or LWIR sensor consists of a large number of individual research topics. Table 1 below summarizes the results of this research project in its current state. The 1st column in Table 1 is a list of all of the research topics, the 2nd column indicates their status (note that five are still being researched), the next four columns assess performance superiority based upon the research results, and the rightmost two columns indicate whether those results point to a 3rd Gen FLIR or to a single band FLIR as the best level of performance for a U.S. soldier in the field. The logic of that choice is as follows: if one specific band or availability of both bands provide the best performance, then a 3rd Gen FLIR wins; however, if either MWIR or LWIR would suffice equally, then a single band FLIR wins.

Even though all of the research listed in Table 1 has not yet been completed, NVESD has clearly established that 3rd Gen FLIR provides a significant operational performance advantage over a single band MWIR or LWIR sensor alone. It is true that many 3rd Gen performance benefits are due to particular cases and not the average performance of the system; however, these particular cases occur frequently enough in tactical situations that they overwhelmingly warrant the availability of both bands. A great deal of research has been conducted and the primary benefits of 3rd Gen FLIR are becoming clear. There is still a large amount of work left, and NVESD will continue to research and publish the remaining topics.

Research Topic	Work in Progress	MWIR Superior	LWIR Superior	Either (Same)	MWIR + LWIR	3rd Gen	Single Band
Long Range Target Identification (ID)		X				✓	
AiTR Performance: MWIR Day Vs Night					X	✓	
AiTR Performance: 2-Band Vs 1-Band					X	✓	
Burning Barrels, Dynamic Range, Blooming, and Veiling Glare			X			✓	
Conventional Target Contrast					X	✓	
Human Target Contrast					X	✓	
Conventional and Urban Background Contrast					X	✓	
Conventional Search and Detection					X	✓	
Urban Search	X						
Advanced Signal Processing: LCE and Boost				X			✓
Cold Weather Performance			X			✓	
Turbulence					X	✓	
Integration Time			X			✓	
Camouflage	X						
Spectral Exploitation of Conventional Targets	X						
Spectral Exploitation of Urban Targets	X						
Smoke					X	✓	
Pilotage	X						
Wet Targets				X			✓
Path Radiance					X	✓	

Table 1. 3rd Gen FLIR performance research topics

REFERENCES

1. V. Hodgkin, B. Kowalewski, D. Tomkinson, B. Teaney, T. Corbin, R. Driggers, "Modeling of IR Sensor Performance in Cold Weather," SPIE Defense and Security Symposium, Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XVII, Orlando, FL, April 2006.
2. P. Richardson, "Turbulence Effects on 3rd Generation FLIR Performance," SPIE Defense and Security Symposium, Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XVII, Orlando, FL, April 2006.
3. Karin R.Weiss-Wrana, "Turbulence Statistics Applied to Calculate Expected Turbulence-Induced Scintillation Effects on Electro-Optical Systems in Different Climate Regions", Proceedings of SPIE, Vol. 5237, pp 1-12, 2004, Bericht FGAN-FOM 2003/11.
4. B. Miller, P. Richardson, R. Driggers, "Detector Integration Time Effects on 3rd Generation FLIR Performance," SPIE Defense and Security Symposium, Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XVII, Orlando, FL, April 2006.