Background temperature effect to range performance of large F-number uncooled infrared cameras

P. Laou

Defence Research and Development Canada

Scientific Report
DRDC-RDDC-2014-R52
August 2014

Background temperature effect to range performance of large F-number uncooled infrared cameras

P. Laou

Defence Research and Development Canada

Scientific Report
DRDC-RDDC-2014-R52
August 2014

IMPORTANT INFORMATIVE STATEMENTS

This work was supported under WBE 10cd09 “IR technologies” and 10cd11 “Novel designs for IR detectors to optimize DRI”, and was conducted between September 2012 and January 2014.

Abstract

In earlier studies, it was shown in modeling that range performance of cameras with high resolution detectors could outperform those with lower resolution, even with larger F# optics (For example F#>1). However, background temperature of the scene, which affects the sensitivity of detectors, was not considered in these studies.

In this work, range performance of uncooled infrared imaging systems were estimated with the use of NvThermIP tool with background temperature consideration. We showed that uncooled IR imaging systems with small pixel pitch, high resolution FPAs could outperform those with larger pitch FPAs at lower resolution in targeting tasks. This is still valid even (1) with negative impact to detail resolving performance from diffraction effect caused by smaller pitch and larger F#; (2) with negative impact to signal throughout caused by larger F#; and (3) with negative impact to FPA thermal sensitivity caused by lower background temperatures. These results mean that, for some applications such as soldier systems, acceptable range performance even in cold weather can be obtained from compact, lightweight infrared imaging systems with the use large F# optics, and high resolution, small pixel pitch detector arrays.

Significance to defence and security

High performance, compact and light weight infrared imaging devices and systems can be realised with the use of high resolution, small pixel pitch detector arrays. The trend toward high resolution and small pixel pitch detector arrays will address two important requirements: (1) range performance with enhanced target details for target recognition/identification and/or with increased standoff target detection/recognition/identification range; (2) compact, lightweight infrared imaging devices and systems.

Résumé

Des études faites auparavant ont démontré par modélisation que la portée de caméras munies de détecteurs à haute résolution pouvait être supérieure à celle de caméras munies de détecteurs à résolution moindre, et ce, malgré des éléments optiques à nombre d'ouverture (f/) plus élevé (p. ex., f/ supérieur à 1). Toutefois, ces études ne tenaient pas compte de la température de fond de la scène, qui influe sur la sensibilité des détecteurs.

Durant les travaux, nous avons utilisé l'outil NvThermIP pour estimer la portée de systèmes d'imagerie infrarouge (IR) non refroidis, en tenant compte de la température de fond. Pour les tâches de ciblage, nous avons démontré que la portée de systèmes d'imagerie IR non refroidis dotés de matrices à plan focal (MPF) à haute résolution et à petit pas de pixel pouvait être supérieure à celle de systèmes dotés de MPF dont le pas de pixel est plus grand et la résolution, plus basse. Cette constatation est valide malgré les répercussions négatives 1) sur la détection de détails, en raison de l'effet de diffraction créé par le pas de pixel plus petit et le f/ plus élevé, 2) sur le débit de traitement de signal, en raison du f/ plus élevé, et 3) sur la sensibilité thermique de la MPF, en raison d'une température de fond moins élevée. D'après les résultats obtenus, les systèmes d'imagerie IR légers et compacts munis de réseaux de détecteurs à petit pas de pixel, à haute résolution et à éléments optiques à f/ plus élevé peuvent permettre d'obtenir une portée acceptable pour certaines applications, comme les systèmes du soldat, et ce, même par temps froid.

Importance pour la défense et la sécurité

On peut concevoir des systèmes et des dispositifs d'imagerie IR légers, compacts et à rendement élevé à l'aide de réseaux de détecteurs à petit pas de pixel et à haute résolution. La tendance vers ce type de réseaux de détecteurs permettra de satisfaire deux besoins importants, c'est-à-dire 1) obtenir une portée avec des détails d'objectifs rehaussés aux fins d'identification et de reconnaissance d'objectifs ou une portée supérieure pour l'identification, la reconnaissance et la détection d'objectifs à distance de sécurité (ou les deux) et 2) créer des systèmes et des dispositifs d'imagerie IR légers et compacts.

Table of contents

List of figures

List of tables

This page intentionally left blank.

1 Introduction

1.1 State-of-the-art of existing uncooled infrared imaging technologies

Infrared imaging technologies for surveillance and reconnaissance continue to mature with innovations across all major components: detectors, optics, electronics and image processing technologies. For example, the newest uncooled infrared focal plane arrays (FPAs) are at a resolution of 1024 by 768 (XGA) with a pixel pitch of 17 µm with a sensitivity or Noise Equivalent Temperature Difference (NETD) below 50mK. The increased resolution and the small pixel pitch make possible to realise an imaging system with increased target detection and recognition ranges (D/R). With smaller detector array from reduced pixel pitch size, it is now possible to build a more compact and light weight system due to the fact that a smaller front optics could be used without increasing the system optical F-number (F#). According to US Night Vision Laboratory back in 2010, the trend is to reach 12 µm pixel pitch in a few years. The enhanced sensitivity also allows the use of yet larger F# or smaller optical aperture resulting in reduction of system size and weight without significant impact on range performance.

According to recent conversations with suppliers at OPTRO2012 in Paris, for example, AIM is expecting demonstrations of cooled FPAs with 12 to 15 µm pitch in 2013 and 10 µm pitch FPAs in 2014. ULIS is also working on 10 µm pixel pitch in uncooled infrared FPAs at R&D level with working prototypes at 10 µm pitch possibly available in two to three years' time. From this point, it is a general consensus that ongoing industrial efforts are to continue increasing the FPA spatial resolution and also to reduce the pixel pitch for the reasons mentioned above [1].

Note: Sofradir has unveiled its new Daphnis-HD (1280×720) cooled FPA detector modules with 10 µm pixel pitch at the SPIE's Defense, Security and Sensing in Baltimore MD in May 2014.

1.2 Background temperature and F-number of uncooled IR cameras

In order to benefit from the progress of high resolution and small pitch detector FPAs, optical systems of these cameras should be designed accordingly. In addition, there are potentially emerging alternatives which might become feasible with the small pitch and increased resolution FPAs.

In general, the optics of uncooled IR cameras was traditionally configured to F/1. The main reason is that sensitivity (NETD) of uncooled cameras is only moderate, as a result, high signal throughput is required for acceptable image quality and range performance. High signal throughput means low F#. To demonstrate this idea, the sensitivity, or NETD of an uncooled camera, is a function of F# of its optics:

$$\text{NETD} \propto (F\#)^2$$

In earlier studies [2-4], it was shown in modeling that range performance of cameras with high resolution detectors could outperform those with lower resolution, even with larger F# optics (For example F#>1). Figures 1 to 3 below are range performance reproduced from [2]. In this simulation, NETD of FPAs of 640×480 (VGA) and 1024×768 (XGA) were taken as 50mK and 80mK, respectively. The pixel pitch varied from 25 to 17 to 12 µm while F# varied from 1 to 2. The field-of-view (FOV) is all at 9.167×6.875 deg.

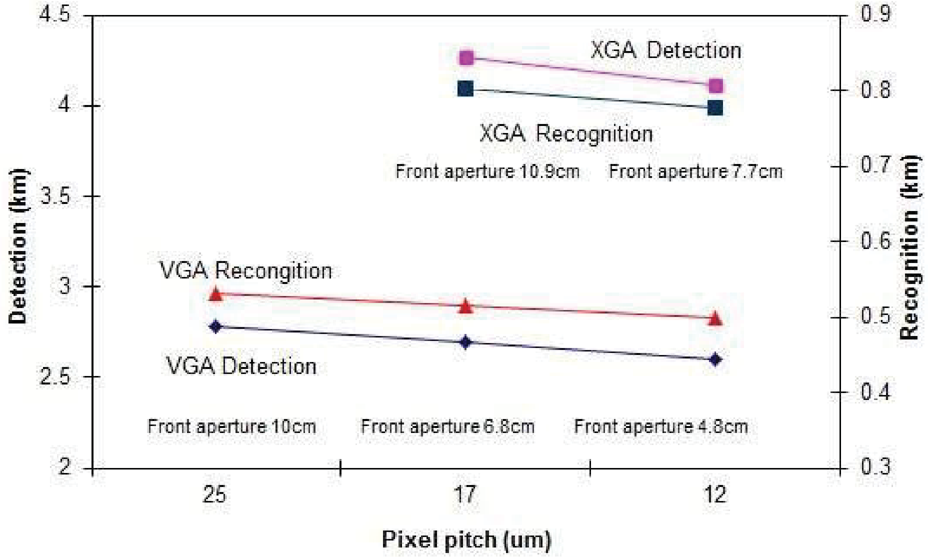

Figure 1: *Target detection and recognition ranges of VGA and XGA imager at F#=1 with 25, 17 and 12µm pixel pitch.*

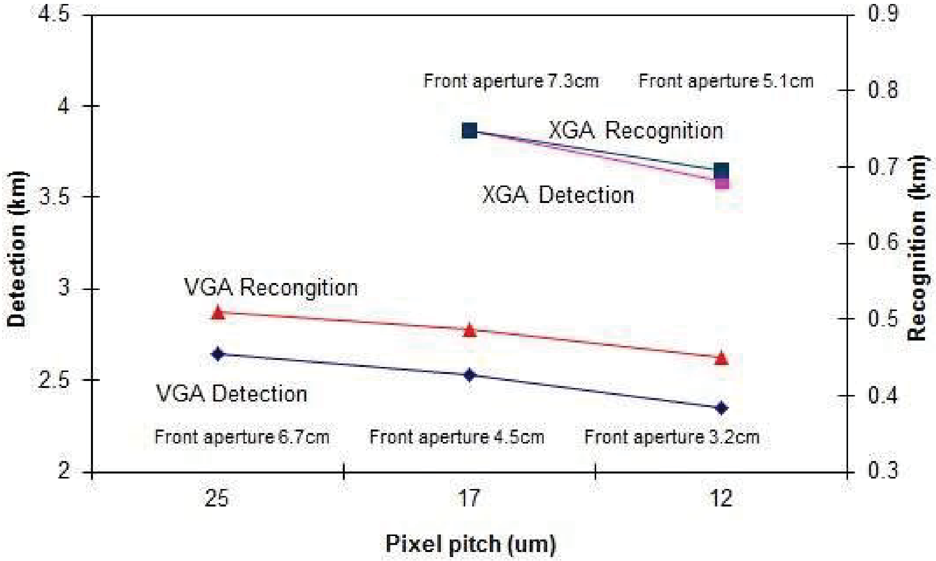

Figure 2: *Target detection and recognition ranges of VGA and XGA imager at F#=1.5 with 25, 17 and 12µm pixel pitch.*

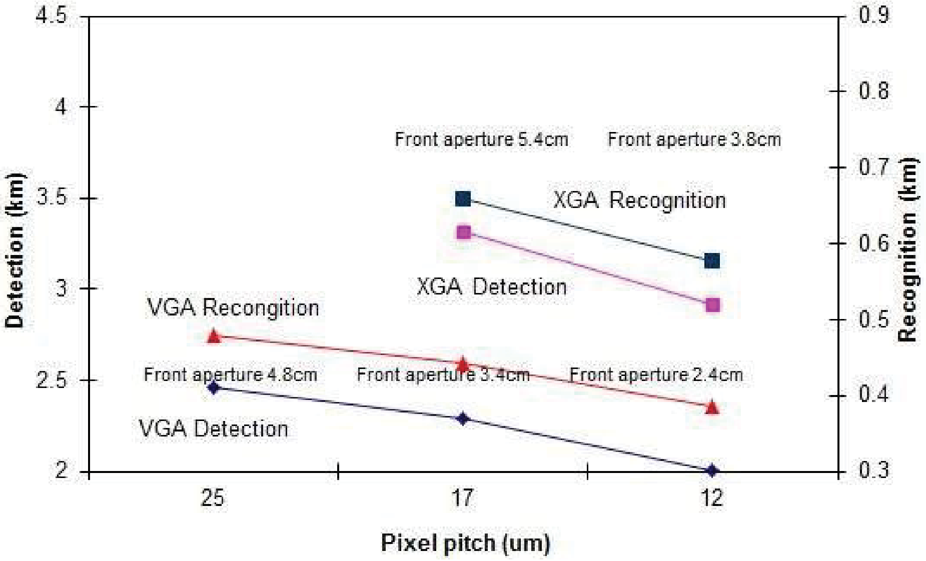

Figure 3: *Target detection and recognition ranges of VGA and XGA imager at F#=2 with 25, 17 and 12µm pixel pitch.*

It was shown that the overall range performance of XGA is superior to that of VGA even at large F#, lower NETD and small pixel pitch. However, background temperature of the scene was not considered in these studies. In fact, NETD of uncooled IR detectors is the change in radiance per unit temperature $\partial L/\partial T$ (Watt/cm^2- sr-K) integrated over a certain wavelength band [5].

$$NETD = \frac{4(F/\#)^2\sqrt{\Delta f}}{\pi \frac{\partial L}{\partial T} D^* \sqrt{A_d}} \tag{1}$$

Δf is the dwell time or bandwidth of the detector, D^* is detector's detectivity, and A_d is detector's area. As L, a function of existence M (Watt/cm^2), decreases as background temperature decreases, $\partial L/\partial T$ will decrease leading to larger NETD or less thermally sensitive detectors.

This work is to study the effect of background temperature to large F# systems, and also verify the advantage of larger F#, high resolution, small pitch uncooled IR cameras over smaller F#, standard resolution uncooled IR cameras. NETD value at 300K background temperature and several others modified for different background temperatures (Equation (1)) were used to estimate range performance using NvThermIP tool. FPA resolution, NETD values and corresponding F# were used in the range performance analysis.

This work was supported under WBE 10cd09 "IR technologies" and 10cd11 "Novel designs for IR detectors to optimize DRI", and was conducted between September 2012 and January 2014.

2 System and simulation parameters

Specification of several uncooled imaging systems was proposed here for range performance estimation based on NvThermIP tool. The specification of interest is FPA resolution, NETD of FPAs, optical aperture dimension of the imaging systems, and its F# and FOV. Their range performance was calculated for several background temperatures from which NETD was modified according to Equation (1).

2.1 System parameters

Three existing uncooled IR FPAs plus a potentially upcoming FPA were selected for this study. These FPAs and their associated system parameters were listed in Table 1.

Table 1: *Several system configurations.*

Configuration	I	II	III	IV
FPA resolution	640×480	640×480	1024×768	1024×768
Pixel pitch (μm)	17	25	17	12
NETD (mK) 300K background	50	50	50	50
FOV (degrees)	8×6	8×6	8×6	8×6

Regarding the choice of FPA specification, FPA resolution of 640×480 and 1024×768 exists at pixel pitches of 17 and 25μm. These existing FPAs provide sensitivity of around 50mK. In addition, FOV of 8×6 degrees were configured in many handheld surveillance systems and weapon mounted weapon sights mainly for range performance and system weight tradeoff. FPA of pixel pitch at 12μm does not exist, however, it is reasonable to believe that this will be available in very near future.

2.2 NETD and background temperature

We need to compute the corresponding FPA NETD at different background temperatures. We assume that the quoted FPA NETD was measured at 300K. By calculating $\partial L/\partial T$ at 300K and other $\partial L/\partial T$ of different background temperatures, we can calculate the corresponding FPA NETD values affected by different background temperatures with Equation (1). It is noted that the system NETD and range performance were estimated with inputs of F#, pixel pitch (A_d), D^* and detector bandwidth in NvThermIP.

By integrating the Plank equation for blackbody spectral existence $M_\lambda(\lambda,T)$ (unit in W/cm^2-µm) over 7.7 to 14.0 µm at 300K in the case of LWIR, where

$$M = \pi L \tag{2}$$

$\partial L/\partial T$ is computed at about 9.17×10^{-5} Watt/cm^2-Ster-K.

For other background temperatures: 310, 290, 280, 270, 260 and 250K, the corresponding $\partial L/\partial T$ and FPA NETD values are summarized in Table 2.

Table 2: *Change in radiance per unit temperature in LWIR spectral band and corresponding NETD as a function of background temperature.*

Background temperatures (K)	$\partial L/\partial T$ (Watt/cm^2-Ster-K)	NETD (mK)
250	5.15×10^{-5}	89.0
260	5.90×10^{-5}	77.7
270	6.68×10^{-5}	68.6
280	7.49×10^{-5}	61.2
290	8.32×10^{-5}	55.1
300	9.17×10^{-5}	50.0
310	1.00×10^{-4}	45.9

The estimated NETD increases as background temperature decreases. The explanation is that NETD is defined as the temperature difference (ΔT) for which the signal-to-noise ratio (SNR) equals to 1 where the signal is proportional to radiance L (watt/cm^2-ster) while noise level is known. As L (watt/cm^2-ster) and $\partial L/\partial T$ (Watt/cm^2-Ster-K) decreases at lower background temperature, a larger ΔT or NETD is required to achieve a SNR=1. This means the detector is less sensitive at low background temperature and this is shown in Table 2.

2.3 NvThermIP simulation parameters

The range performance analysis based on NvThermIP tool used the system configurations shown in Table 1. In addition, NETD values shown in Table 2 and different F# values were considered in the analysis. Based on the selected FOVs and F#, we determined the focal lengths (FL) and then front aperture diameters or effective pupil diameter (EPD) for the simulation. Human size target with a 2K contrast and V50 DRI criteria were used.

Other assumptions were summarized below.

- 60 frames per second
- No fixed pattern noise
- No electronics processing and no MTF modification (Assuming diffraction limited system)
- 90% optical transmission
- Distance taken at 50% probability of detection (D), recognition (R), identification (I)
- V_{50} Targeting Task Performance (TTP) – 2.7 cycles for detection, 14.5 cycles for recognition, 18.78 cycles for identification
- Without Chance Factor in target recognition
- Target area 0.75 m^2 (0.85×0.85 m) for a man-size target
- Target-background temperature contrast at two degrees
- Turbulence C_n^2 10^{-14} $m^{-2/3}$
- ModTran model – Zero attitude, no aerosol, US Standard 1976
- No smoke and obscurants
- Gain varies with range
- Display – Display spot size or pixel size at 0.03mm; Display height or image height equal to horizontal number of pixels times pixel size; Viewing distance is 38.1cm

Note: These display parameters would result in different image magnification for viewing with the use of FPA resolutions and pixel pitch sizes. However, as long as the magnification is above 1 [6], this would only contribute to slight variation on range performance estimation and would not cause conflicting arguments. The magnification is 3.61 for the 640×480 FPA and 5.78 for the 1024×768 FPA in this study. In addition, the difference in range performance was shown here to be significant to demonstrate potential advantages of resolution on targeting tasks.

3 Range performance

NvThermIP modeling was performed to estimate range performance of several configurations of uncooled IR systems at different background temperatures as defined in Chapter 2. Range performance of these configurations was considered with F# at 1, 2, 3 and 4.

3.1 NvThermIP simulation results

Configuration I:

The dimension of FPA (640×480 17μm pitch): 10.88mm by 8.16mm

FOV= 8×6 degrees

FL=77.9mm

Table 3: *Range performance (D/R) in km under various F# and background temperatures of configuration I.*

Background temperature (K) / Equivalent FPA NETD (mK)	F#=1 (EPD=77.9mm)	F#=2 (EPD=39.0mm)	F#=3 (EPD=26.0mm)	F#=4 (EPD=19.5mm)
250 (89)	3.06 / 0.58	2.36 / 0.46	1.52 / 0.31	0.95 / 0.19
260 (78)	3.07 /0.58	2.43 / 0.47	1.61 / 0.32	1.02 / 0.20
270 (69)	3.08 / 0.58	2.49 / 0.48	1.69 / 0.354	1.0 8/ 0.22
280 (61)	3.08 / 0.58	2.54 / 0.49	1.77 / 0.35	1.14 / 0.23
290 (55)	3.09 / 0.58	2.58 / 0.49	1.82 / 0.36	1.19 / 0.24
300 (50)	3.09 / 0.58	2.61 / 0.50	1.87 / 0.37	1.25 / 0.25
310 (46)	3.09 / 0.58	2.64 / 0.50	1.92 / 0.38	1.28 / 0.26

Configuration II:

The dimension of FPA (640×480 25μm pitch): 16mm by 12mm

FOV= 8×6 degrees

FL=114.6mm

***Table 4:** Range performance (D/R) in km under various F# and background temperatures of configuration II.*

Background temperature (K) / Equivalent FPA NETD (mK)	F#=1 (EPD=114.6mm)	F#=2 (EPD=57.3mm)	F#=3 (EPD=38.2mm)	F#=4 (EPD=28.7mm)
250 (89)	3.15 / 0.59	2.54 / 0.50	1.83 / 0.37	1.24 / 0.26
260 (78)	3.16 / 0.59	2.61 / 0.51	1.92 / 0.39	1.32 / 0.27
270 (69)	3.17 / 0.59	2.67 / 0.52	2.01 / 0.40	1.40 / 0.29
280 (61)	3.17 / 0.59	2.73 / 0.53	2.09 / 0.42	1.48 / 0.30
290 (55)	3.18 / 0.59	2.77 / 0.53	2.16 / 0.43	1.55 / 0.32
300 (50)	3.18 / 0.60	2.80 / 0.54	2.22 / 0.44	1.62 / 0.33
310 (46)	3.18 / 0.60	2.83 / 0.54	2.27 / 0.45	1.68 / 0.34

Configuration III:

The dimension of FPA (1024×768 17μm pitch): 17.4mm by 13.1mm

FOV= 8×6 degrees

FL=124.6mm

***Table 5:** Range performance (D/R) in km under various F# and background temperatures of configuration III.*

Background temperature (K) / Equivalent FPA NETD (mK)	F#=1 (EPD=124.6mm)	F#=2 (EPD=62.3mm)	F#=3 (EPD=41.5mm)	F#=4 (EPD=31.2mm)
250 (89)	4.85 / 0.92	3.67 / 0.73	2.35 / 0.48	1.48 / 0.30
260 (78)	4.88 / 0.93	3.79 / 0.75	2.48 / 0.51	1.58 / 0.32
270 (69)	4.89 / 0.93	3.89 / 0.77	2.60 / 0.53	1.68 / 0.34
280 (61)	4.91 / 0.93	3.98 / 0.78	2.73 / 0.55	1.77 / 0.36

Background temperature (K) / Equivalent FPA NETD (mK)	F#=1 (EPD=124.6mm)	F#=2 (EPD=62.3mm)	F#=3 (EPD=41.5mm)	F#=4 (EPD=31.2mm)
290 (55)	4.92 / 0.93	4.05 / 0.79	2.83 / 0.57	1.85 / 0.38
300 (50)	4.92 / 0.93	4.11 / 0.79	2.91 / 0.59	1.93 / 0.39
310 (46)	4.93 / 0.93	4.15 / 0.80	2.98 / 0.60	2.00 / 0.40

Configuration IV:

The dimension of FPA (1024×768 12μm pitch): 12.3mm by 9.2mm

FOV= 8×6 degrees

FL=88.1mm

Table 6: *Range performance (D/R) in km under various F# and background temperatures of configuration IV.*

Background temperature (K) / Equivalent FPA NETD (mK)	F#=1 (EPD=88.1mm)	F#=2 (EPD=44.1mm)	F#=3 (EPD=29.4mm)	F#=4 (EPD=22.0mm)
250 (89)	4.68 / 0.89	3.23 / 0.65	1.84 / 0.38	1.10 / 0.23
260 (78)	4.70 / 0.89	3.33 / 0.67	1.95 / 0.39	1.17 / 0.25
270 (69)	4.72 / 0.89	3.42 / 0.68	2.04 / 0.41	1.25 / 0.27
280 (61)	4.73 / 0.90	3.51 / 0.69	2.13 / 0.43	1.32 / 0.28
290 (55)	4.74 / 0.90	3.57 / 0.70	2.21 / 0.45	1.38 / 0.30
300 (50)	4.75 / 0.90	3.62 / 0.71	2.28 / 0.46	1.44 / 0.31
310 (46)	4.75 / 0.90	3.66 / 0.71	2.33 / 0.47	1.48 / 0.32

3.2 Analysis

(i) By comparing the range performance of the four configurations, it is clear that the maximum standoff ranges of target detection and recognition (D/R) decrease as F# increases.

(ii) The reduction of background temperatures from 310 to 250K has less effect to DR tasks in all configurations with F/1 optics. The most reduction in DR task performance was obtained in configurations at F/4. This is summarized in Table 7. This means range performance of system with large F# optics is more susceptible (up to 23-24% reduction at F/4) to change of background temperature.

Table 7: *D/R task range reduction of configurations I to VI between 300 and 250K background temperature.*

Configuration I				
	F#=1	F#=2	F#=3	F#=4
D/R task performance decreases (%) from background temperature 300K to 250K	0.97 / 0.0	9.58 / 8.00	18.72 / 16.22	24.00 / 24.00
Configuration II				
D/R task performance decreases (%) from background temperature 300K to 250K	0.94 / 1.67	10.25 / 8.00	17.57 / 15.90	23.46 / 21.21
Configuration III				
D/R task performance decreases (%) from background temperature 300K to 250K	1.42 / 1.09	10.71 / 7.59	19.24 / 18.64	23.32 / 23.08
Configuration IV				
D/R task performance decreases (%) from background temperature 300K to 250K	1.47 / 1.11	10.77 / 8.45	19.30 / 17.39	23.61 / 25.81

(iii) Again referring to Table 7, it showed that the change of background temperatures has about the same impact to all configurations, within 1 to 2% different for detection task and up to 4% for recognition task under the same F# in each configuration, i.e. it is independent to resolution and pixel size.

There are other observations.

(iv) With the same angular resolution between configurations I and II (and between configurations III and IV as well), the range performance of 25 µm pitch FPA is slightly superior to that of 17 µm pitch which is also slightly superior to that of 12 µm pitch. This is due to the fact that diffraction effect began dominant in smaller pixel pitch and contributing degradation to resolvable details.

(v) Table 8 illustrates the effect to system range performance from background temperatures. It showed more severe, negative effect to range performance at elevated F# among the four configurations at various background temperatures, from 50 to 77% at F/4. The overall reduction in range performance between F/1 and F/4 at background temperature 250-300K is shown to be 3-10 %, which added to the observation in Point (iii) that background temperature poses less negative impact than that of F# to D/R range performance.

Table 8: *D/R task range reduction of configurations I to VI from F/1 to F/4 under various background temperatures.*

Configuration I				
	Background temp = 300K	Background temp = 280K	Background temp = 260K	Background temp = 250K
D/R task performance decreases (%) from F/1 to F/4	59.55 / 56.90	62.99 / 60.34	66.78 / 65.52	68.95 / 67.24
Configuration II				
D/R task performance decreases (%) from F/1 to F/4	49.06 / 45.00	53.31 / 49.15	58.23 / 54.24	60.63 / 55.93
Configuration III				
D/R task performance decreases (%) from F/1 to F/4	60.77 / 58.06	63.95 / 61.29	67.62 / 65.59	69.48 / 67.39
Configuration IV				
D/R task performance decreases (%) from F/1 to F/4	69.68 / 65.56	72.09 / 68.89	75.11 / 71.91	76.50 / 74.16

(vi) Also shown in Table 8, small pixel pitch is more susceptible to range performance degradation at elevated F#. The reduction in range performance in Configuration II (25µm pitch) is less than those in Configuration I (17µm pitch) while range performance reduction is larger in Configuration IV (12µm pitch) than in Configuration III (17µm pitch).

(vii) On the other hand, smaller pixel pitch FPAs make possible of higher resolution FPAs for increased angular resolution, which would overcome the impact of large F#. This idea is illustrated in Figures 4 and 5 where the range performance of FPA at 640×480 resolution at 300K background temperature were plotted against those of FPA at 1024×768 resolution at 250K background temperature. It is clearly shown that range performance of XGA FPAs at 12 and 17µm are superior to those of VGA, even at background temperature of 250K and larger than F/2.

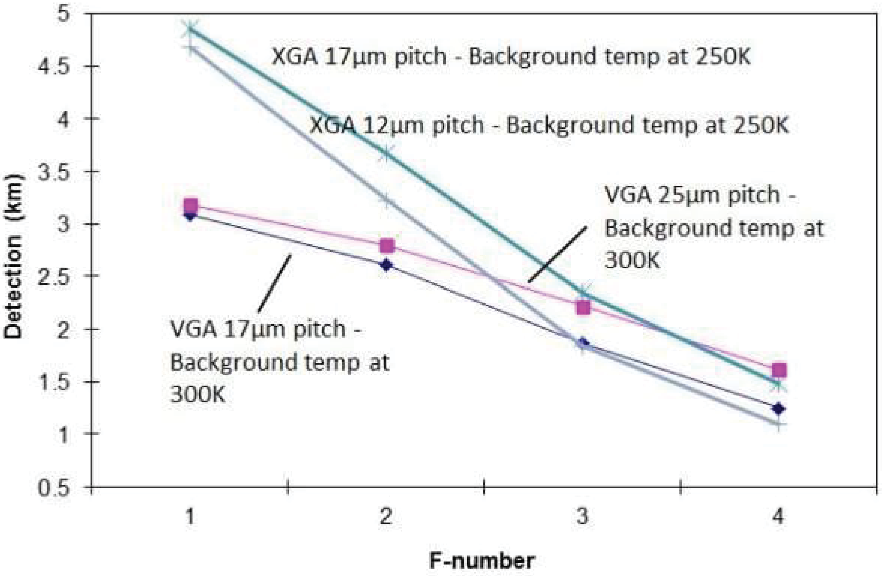

Figure 4: *Range performance of target detection of VGA at 300K background temperatures and XGA at 250K background temperature with F# from 1 to 4.*

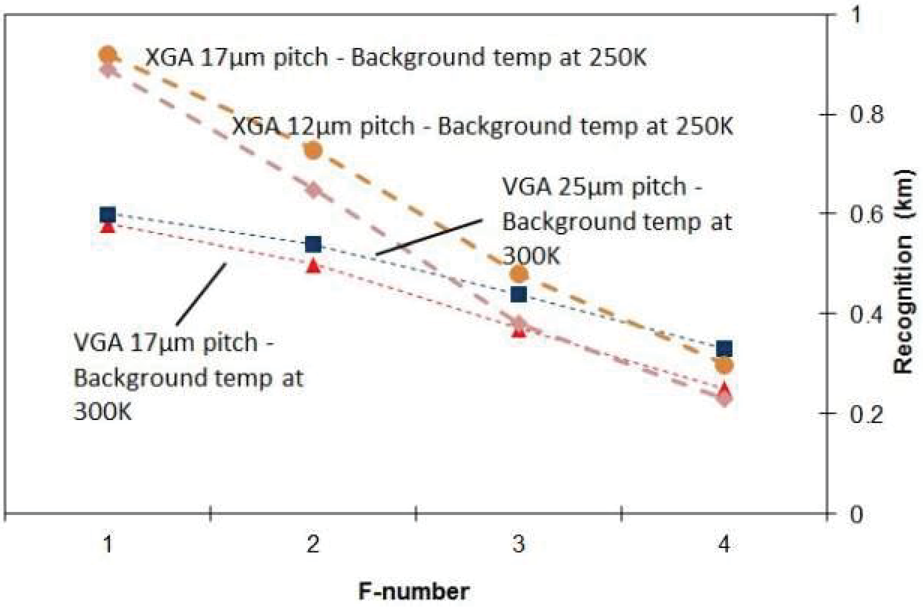

Figure 5: *Range performance of target recognition of VGA at 300K background temperatures and XGA at 250K background temperature with F# from 1 to 4.*

(viii) Also referring to Figures 4 and 5, the gain on range performance from high resolution FPA (higher angular resolution) begins to disappear toward F/3 with the consideration of background temperatures, as reported in [2-4]. Here, we showed that this is still valid at low background temperatures.

4 Discussion and conclusion

In this work, we showed that uncooled IR imaging systems with small pixel pitch, high resolution FPAs could outperform those with larger pitch FPAs at lower resolution in targeting tasks. This is still valid even (1) with negative impact to detail resolving performance from diffraction effect caused by smaller pitch and larger F#; (2) with negative impact to signal throughout caused by larger F#; and (3) with negative impact to FPA thermal sensitivity caused by lower background temperatures.

Assuming other parameters (optics, detectors, electronics, display) are optimized, it is clear that an IR system with the lowest F# around 1 would provide nearly the best range performance. However, a more compact, lightweight system with acceptable range performance may be preferred according to specific applications. The possibility of adopting larger F# with the use of small pitch, high resolution FPA in the design may provide an alternative solution.

Some range performance from Table 3 to 6 were selected and showed in Table 9. These are the observations:

Table 9: *Selected D/R range performance of configurations I to VI from Tables 3 to 6.*

Configuration I (FL=77.9mm)				
	F#=1 (EPD=77.9mm)	F#=2 (EPD=39.0mm)	F#=3 (EPD=26.0mm)	F#=4 (EPD=19.5mm)
D/R task performance at 300K	3.09 / 0.58	2.61 / 0.50	1.87 / 0.37	1.25 / 0.25
Configuration II (FL=114.6mm)				
	F#=1 (EPD=114.6mm)	F#=2 (EPD=57.3mm)	F#=3 (EPD=38.2mm)	F#=4 (EPD=28.7mm)
D/R task performance at 300K	3.18 / 0.60	2.80 / 0.54	2.22 / 0.44	1.62 / 0.33
Configuration III (FL=124.6mm)				
	F#=1 (EPD=124.6mm)	F#=2 (EPD=62.3mm)	F#=3 (EPD=41.5mm)	F#=4 (EPD=31.2mm)
D/R task performance at 250K	4.85 / 0.92	3.67 / 0.73	2.35 / 0.48	1.48 / 0.30
Configuration IV (FL=88.1mm)				
	F#=1 (EPD=88.1mm)	F#=2 (EPD=44.1mm)	F#=3 (EPD=29.4mm)	F#=4 (EPD=22.0mm)
D/R task performance at 250K	4.68 / 0.89	3.23 / 0.65	1.84 / 0.38	1.10 / 0.23

(i) By comparing configurations I and II, range performance is similar at around F/2. The FL and EPD of configuration I are 32% shorter and smaller. This implies a smaller, lighter optics for configuration I with 17µm pitch FPA.

(ii) By comparing configurations III and IV, range performance is similar only at and near F/1. The FL and EPD of configuration IV are 29% shorter and smaller. This implies a smaller, lighter optics for configuration I with 12µm pitch FPA.

(iii) By comparing configurations III to I and II, range performance of configuration III is superior to those of I and II at F/1, even at F/2 and at 250K background temperature. At F/2, EPD of configuration III is smaller than those of I and II at F/1. This implies a smaller, lighter optics in configuration III.

(iv) By comparing configurations IV to I and II, range performance of configuration IV is superior to those of I and II at F/1, even at F/2 and at 250K background temperature. At F/2, the FL and EPD of configuration IV are 43 and 62% shorter and smaller than those of I and II at F/1, respectively. This implies a smaller, lighter optics in configuration IV.

Finally, advantages of extreme high resolution, small pixel pitch FPA was described and analysed in [1]. In these scenarios, the IR system will be smaller even with small F#. Multiple FOV capability of acceptable details can be realized simply with electronic zoom without the use of physically switchable optics.

This page intentionally left blank.

References

[1] Driggers, R., Holst, G., Reynolds, J., Fanning, J. and Vollmerhausen, R. (2012). Infrared detector size – How low should you go? Proceedings of SPIE: Infrared Imaging Systems: design, analysis, modeling, and testing XXIII Vol. 8355, SPIE Defense, Security + Sensing 2012, April 23-27 2012.

[2] Laou, P. (2010). Performance analysis of uncooled infrared surveillance systems regarding pixel pitch of detector arrays and optical F-number. DRDC Valcartier TN 2010-56. Defence R&D Canada.

[3] Laou, P., St-Germain, D, Mérel, P., Paradis, S., Roy, N. and Maheux, J. (2011). Infrared technologies and task performance. DRDC Valcartier TM 2011-230. Defence R&D Canada.

[4] Laou, P., St-Germain, D., Côté, M. and Côté, J. (2013). Novel image mapping on focal plane array of optronic system for enhanced targeting task performance. DRDC Valcartier TM 2013-183. Defence R&D Canada.

[5] Laou, P. (2008). Uncooled thermal detector performance in MWIR and shorter wavelengths: A new perspective in the future. DRDC Valcartier TN 2008-290. Defence R&D Canada.

[6] Tremblay, G. (2011). Characterization of NvThermIP range performance prediction sensitivity to input parameters. DRDC Contract Report. W7701-091884. AEREX Report Number: 2011-91884-AT5-1.

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security markings for the title, abstract and indexing annotation must be entered when the document is Classified or Designated)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g., Centre sponsoring a contractor's report, or tasking agency, are entered in Section 8.)

Defence Research and Development Canada – Valcartier
2459 Pie-XI Blvd North
Quebec (Quebec)
G3J 1X5 Canada

2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.)

UNCLASSIFIED

2b. CONTROLLED GOODS

(NON-CONTROLLED GOODS)
DMC A
REVIEW: GCEC DECEMBER 2012

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Background temperature effect to range performance of large F-number uncooled infrared cameras

4. AUTHORS (last name, followed by initials – ranks, titles, etc., not to be used)

Laou, P.

5. DATE OF PUBLICATION (Month and year of publication of document.)

August 2014

6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)

31

6b. NO. OF REFS (Total cited in document.)

6

7. DESCRIPTIVE NOTES (The category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g., interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Scientific Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence Research and Development Canada – Valcartier
2459 Pie-XI Blvd North
Quebec (Quebec)
G3J 1X5 Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)

10cd09;10cd11

9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DRDC-RDDC-2014-R52

10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

In earlier studies, it was shown in modeling that range performance of cameras with high resolution detectors could outperform those with lower resolution, even with larger F# optics (For example F#>1). However, background temperature of the scene, which affects the sensitivity of detectors, was not considered in these studies.

In this work, range performance of uncooled infrared imaging systems were estimated with the use of NvThermIP tool with background temperature consideration. We showed that uncooled IR imaging systems with small pixel pitch, high resolution FPAs could outperform those with larger pitch FPAs at lower resolution in targeting tasks. This is still valid even (1) with negative impact to detail resolving performance from diffraction effect caused by smaller pitch and larger F#; (2) with negative impact to signal throughout caused by larger F#; and (3) with negative impact to FPA thermal sensitivity caused by lower background temperatures. These results mean that, for some applications such as soldier systems, acceptable range performance even in cold weather can be obtained from compact, lightweight infrared imaging systems with the use large F# optics, and high resolution, small pixel pitch detector arrays.

Des études faites auparavant ont démontré par modélisation que la portée de caméras munies de détecteurs à haute résolution pouvait être supérieure à celle de caméras munies de détecteurs à résolution moindre, et ce, malgré des éléments optiques à nombre d’ouverture (f/) plus élevé (p. ex., f/ supérieur à 1). Toutefois, ces études ne tenaient pas compte de la température de fond de la scène, qui influe sur la sensibilité des détecteurs.

Durant les travaux, nous avons utilisé l’outil NvThermIP pour estimer la portée de systèmes d’imagerie infrarouge (IR) non refroidis, en tenant compte de la température de fond. Pour les tâches de ciblage, nous avons démontré que la portée de systèmes d’imagerie IR non refroidis dotés de matrices à plan focal (MPF) à haute résolution et à petit pas de pixel pouvait être supérieure à celle de systèmes dotés de MPF dont le pas de pixel est plus grand et la résolution, plus basse. Cette constatation est valide malgré les répercussions négatives 1) sur la détection de détails, en raison de l’effet de diffraction créé par le pas de pixel plus petit et le f/ plus élevé, 2) sur le débit de traitement de signal, en raison du f/ plus élevé, et 3) sur la sensibilité thermique de la MPF, en raison d’une température de fond moins élevée. D’après les résultats obtenus, les systèmes d’imagerie IR légers et compacts munis de réseaux de détecteurs à petit pas de pixel, à haute résolution et à éléments optiques à f/ plus élevé peuvent permettre d’obtenir une portée acceptable pour certaines applications, comme les systèmes du soldat, et ce, même par temps froid.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g., Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

uncooled infrared detectors, range performance