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Improved Detector Performance Rendering in the Optical Spectral Ranges to Provide Accurate Image

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Abstract

Modern sensor systems have complex sensor assemblies with performance depending on variety of factors. An algorithm presented in this work to provide accurate image rendering in the optical spectral ranges of IR imaging systems. From the images output notice that in long wavelength bandwidth of IR (8-12) µm the image was more clarity without noise. This mean S/N ratio and the Efficiency of detector is bigger than band (1-3) µm. Recommend that this method can be used to improve the performance of the thermal detector which uses in thermal imaging system in any package of wavelength. This algorithm can be store as a code in the cart storage of IR imaging system.

Keywords: Detector, Optical Spectrum, Results, Pixel.

الخلاصة

أنظمة الاستشعار الحديثة تملك تجمعات معقدة لمتحسسات تعتمد على عدة عوامل. تم عرض خوارزمية في هذا العمل لتجهز دقة صورة ملائمة تعمل في نطاقات طيفية بصرية من أنظمة التصوير الحراري. من الصور الناتجة نلاحظ أنه في الحزمة العريضة من الطول الموجي من الأشعة تحت الحمراء (٨-١٢) ميكرون كانت الصورة أكثر وضوحا ومن دون ضوضاء وهذا يعني نسبة S / N وكفاءة كاشف أكبر من الحزمة (١-٣) ميكرون. نوصي بأن هذه الطريقة يمكن استخدامها لتحسين أداء الكاشف الحراري الذي يستخدم في أنظمة التصوير الحراري في أي حزمة من الطول الموجي. هذه الخوارزمية يمكن تخزينها كشفرة في تخزين العربة من نظام التصوير بالأشعة تحت الحمراء.

Introduction

The advent of imaging systems presented the need for simulation to provide accurate image rendering in the optical spectral ranges. Modern sensor systems have complex sensor assemblies with performance depending on variety of factors. This work study some of these factors and its effect on the output images investigates the main characteristics of simulation. The generic seeker types are from non-imaging to full imaging, the seeker was modeled as non-imaging with targets represented as point source at some location within the missiles field-of-view FOV. The IR seeker imaging type was modeled which could represent the entire scene within its field-of-view as a matrix of pixels. The detector spectral coverage could be any waveband between 1 to 15 microns. Initially, the imaging seeker is modeled as a 512×512 pixel detector. However, the resolution of the detector can be reduced to 256×256 or 128×128 or may be increased to 1024×1024. The seeker optics characteristics such as FOV, solid angle and transmission and detector noise-equivalent power (NEP) and signal-to-noise ratio (SNR) are considered for calculating power received at the detector and to estimate the lock-on range[1].

Input Parameters

The most important parameters can input in two ways either selecting input parameters from the pre-stored data sets or entering values manually. The following missile parameters are required for modeling the missile seeker in Table 1.

a) Noise Equivalent Power (NEP) of detector in W/Hz1/2,

b) Signal-to-noise ratio (SNR) of the detectors.
c) Diameter of seeker optics (DO) in millimeters.
d) Focal length (f) of seeker optics in millimeters.
e) Transmission of seeker optics (τ_{opt}).
f) Detector size (d) in millimeters.
g) Detector waveband limits (λ start and λ stop) in micro-meters[1].

Table 1: Missile input parameters[1].

	NEP ($W/Hz^{1/2}$)	SNR	Do (mm)	f (mm)	t_{opt}	d (mm)	λstart (μm)	λstop (μm)
Missile I	1.00E-10	3	60	1	0.7	0.1	8	12
Missile II	1.50E-10	5	70	10	0.8	0.3	3	5
Missile III	2.00E-10	7	50	15	0.9	0.5	3	5
Missile IV	2.50E-10	10	80	20	0.75	0.6	8	12

Experimental

Design of IR optical system

Design of Infrared optical systems is different from day vision systems. Though the optimization techniques for IR lens design remain more or less same IR lens design is mostly carried out in two spectral band (3-5) μm, mid wave infrared (MWIR) and (8-12 μm), known as long wave Infrared (LWIR). This is because, the atmosphere does not transmit complete 3 to 12 μm wave band spectrum. Waveband between 5 to 8 μm is absorbed by the atmosphere. There is a small band of 4 to 4.2 μm, which is also absorbed by the atmosphere. Selection of the wave band remains subjective as both wave bands have their merits and demerits. Mainly for hot and humid and for very long ranges (3-5 μm) wave band is preferred while cold and dusty environment (8-12 μm) wave band is preferred. Optical materials available for these bands are limited, i.e. Germanium, ZnS, ZnSe, AMTIR1 for (8-12 μm) and Germanium, Zns and Silicon for only (3-5 μm) waveband. In IR optical system design, detection parameters depend on these parameters. Once any parameter of detector is changed the same lens system can't be used[2].

Steps to calculate detector voltage

1- Calculate the lens area according to the equation:

$$A = \left[\frac{d.R}{f}\right]^2 \text{ (cm)} \quad (1)$$

2- Calculate the solid angle of the detector, is as follows:

$$\Omega = A/R2 = \pi D^2/4R^2 \text{ (sr)} \quad (2)$$

3- The output voltage of the detector is obtained as the following:

$$V = A\,\Omega\,\mathrm{R}(T)\int_{\lambda 1}^{\lambda 2} \tau_{amp}(\lambda\, \tau_{opt})\,\lambda d\lambda \quad (3)$$

R(T): Represents radiance

τ_{amb} and τ_{opt} represent the spectral transmissivity of atmosphere and optics.

The spectral responsivity value of the beam (1.9-2.9 μm) for the detector (GaAs) and beam (8-12 μm) for the detector (HgCdTe) based on Table 4.

4- The efficiency of the detector calculating from the following equation:

$$Q = \frac{1.24 \times S(\lambda)}{(\lambda)} \quad (4)$$

S(λ): is the spectral responsivity (V/W).

If $\tau_{amb}(\lambda)$, $\tau_{opt}(\lambda)$ and S(λ) are time invariant Systems, the integrals of their wavelength-bandwidths have constant values and a , Ω are also constants. This implies that the output of the detector is directly proportional to the radiance R(T) depending on the temperature.

If the detector is a two-dimensional image detector, the gray level of an IR image is also proportional to the output voltage of the detector. Therefore, it can be said that the radiance R(T) of a certain wavelength-bandwidth regarding the object temperature T is proportional to gray levels of an IR

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image[3]. Geometric configuration of target and detector showed in figure 1.

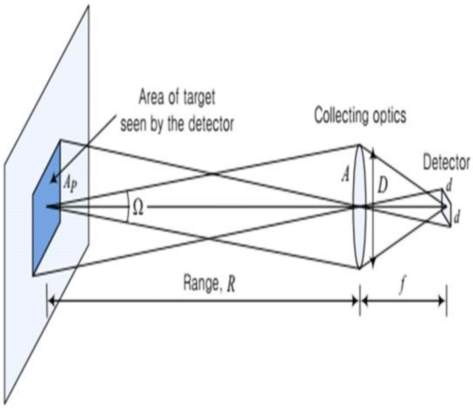

Figure 1: Geometric configuration of target and detector target located at R distance from the IR sensor.

In case L is the lens diameter of the sensor, is A, d, and f represent the lens area, detector size, and focus distance respectively.

Steps to calculate the efficiency of the detector

1- Calculate the detector efficiency based on the equation (4) of the package (1.9-2.9 µm) and (8-12 µm).

2- Compared to the output image (8-12 µm) from previously work, using transformation method, before improving the performance of the detector with output image in (8-12 µm) after improving the performance of the detector. The output results in displayed in Table 2 and most types of infrared detectors and their characteristics taken from Table 3 [4].

3- The final block diagram of procedure showed in Figure 2.

4- The output images before method and output images and after using this method is showed in Figures 3.

Table 2: The output result efficiency of the detector in two bands.

R (cm)	$\tau_{amb}(\lambda)$ **(µm)**	**(Q) at band (1.9-2.9 µm)**	**(Q) at band (8-12 µm)**
15×105	0.6	0.5874	0.310
		0.695	0.5801
		0.789	0.8176
		0.870	1.0280
		0.9424	1.2157
		1.0060	1.3842
		1.0629	1.5363

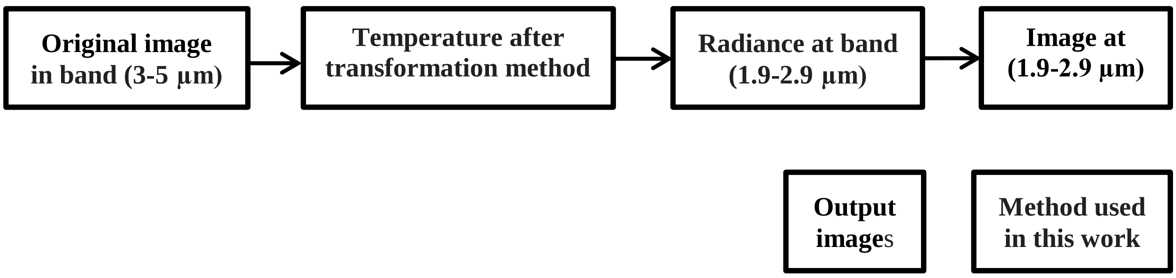

Figure 2: steps of the method.

Table 3: types of infrared detectors and their characteristics[4].

Type			Detector	Spectral response (µm)	Operating temperature (K)	$D^*(cm\cdot Hz^{1/2}/W)$
Thermal type	Thermocouple · Thermopile			Depends on window material	300	D^* (λ,10,1) = 6×10^8
	Bolometer				300	D^* (λ,10,1) = 1×10^8
	Pneumatic cell		Golay cell, condenser-microphone		300	D^* (λ,10,1) = 1×10^9
	Pyroelectric detector		PZT, TGS, $LiTaO^3$		300	D^* (λ,10,1) = 2×10^8
Quantum type	Intrinsic type	Photoconductive type	PbS	1 to 3.6	300	D^* (500,600,1) = 1×10^9
			PbSe	1.5 to 5.8	300	D^* (500,600,1) = 1×10^8
			InSb	2 to 6	213	D^* (500,1200,1) = 2×10^9
			HgCdTe	2 to 16	77	D^* (500,1000,1) = 2×10^{10}
		Photovoltaic type	Ge	0.8 to 1.8	300	D^* (λp) = 1×10^{11}
			InGaAs	0.7 to 1.7	300	D^* (λp) = 5×10^{12}
			Ex. InGaAs	1.2 to 2.55	253	D^* (λp) = 2×10^{11}
			InAs	1 to 3.1	77	D^* (500,1200,1) = 1×10^{10}
			InSb	1 to 5.5	77	D^* (500,1200,1) = 2×10^{10}
			HgCdTe	2 to 16	77	D^* (500,1000,1) = 1×10^{10}
	Extrinsic type		Ge : Au	1 to 10	77	D^* (500,900,1) = 1×10^{11}
			Ge : Hg	2 to 14	4.2	D^* (500,900,1) = 8×10^9
			Ge : Cu	2 to 30	4.2	D^* (500,900,1) = 5×10^9
			Ge : Zn	2 to 40	4.2	D^* (500,900,1) = 5×10^9
			Si : Ga	1 to 17	4.2	D^* (500,900,1) = 5×10^9
			Si : As	1 to 23	4.2	D^* (500,900,1) = 5×10^9

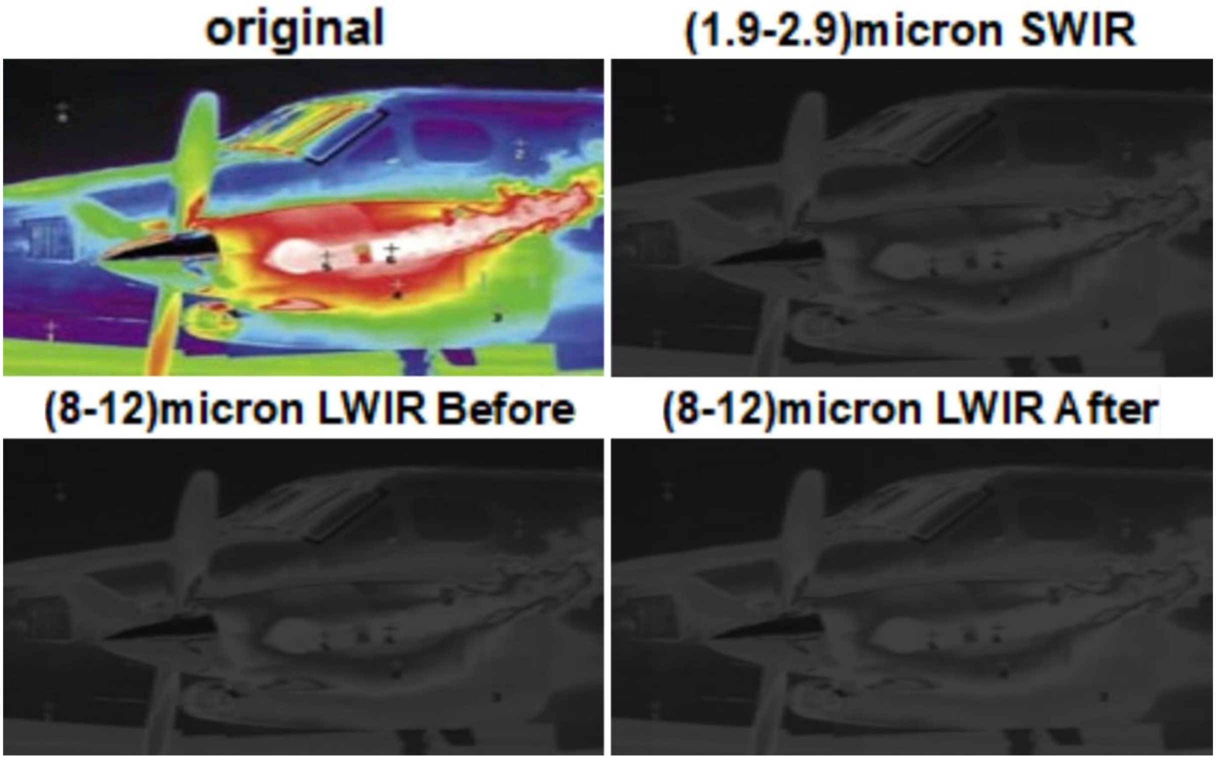

Figure 3: The output images.

Results of Discussion

From the result and the output images after using the method we notice that, the images in the package (1.9-2.9 µm) be more clarity that's means noise will be less.

The ratio S/N and efficiency of the detector shall be greater by the package (8-12 µm) than (1.9-2.9 µm). When compared the images of band (8-12 µm) than previously before improving the performance of the detector notice that there is a difference in clarity and therefore we recommend that this method can be used to improve the performance of the thermal detector, which uses in thermal imaging in any package of wavelength systems. The response of a thermal detector is proportional to the energy absorbed, whereas that of a photon detector is proportional to the number of photons absorb. This algorithm can be store as a code in the cart storage of IR imaging system.

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