COMPARED IMPROVEMENT BY TIME, SPACE AND FREQUENCY DATA PROCESSING OF THE PERFORMANCES OF IR CAMERAS. APPLICATION TO ELECTROMAGNETISM

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Abstract

The thermal resolution of a camera can be improved by time, space and frequency processing. In the first part, the efficiency of such processing is compared for a given camera, using an extended blackbody. In the second part, the processing are applied to the improvement of the radiation pattern determination of an X-band horn using the EMIR technique.

1. Context

The dissemination of the focal plane array technology has allowed a substantial improvement in the sensitivity of the thermographic cameras. Today, NETD near of 20 mK becomes a standard, permitting to enlarge the field of applications of thermography.

Nevertheless, for certain applications, like the characterization of electromagnetic fields, or the observation of strain fields in structures, such performances are not sufficient. There is a need to improve the sensitivity and the signal-to-noise ratio of the thermographic systems. Space and/or time accumulation of images is a means. When possible, working in modulated conditions with lock-in thermographic systems is another possibility. Each approach has positive and negative consequences depending on the application envisaged.

In these conditions, it seems important to give some quantitative comparisons of these approaches, using the same thermographic camera, in a particularly difficult application for which sensitivity and signal-to-noise-ratio are primordial. The chosen application is the characterization of the radiation pattern of an antenna working in the microwave domain.

Finally, some indications related to the data processing strategy to follow, depending on the type of application, can be deduced from this experimental study.

2. Experimental conditions

The IR camera used for this comparative study is the CEDIP Jade LWIR camera (spectral window: 7.7 to 9.7 μm without filters). The flexibility of the camera (windowing from 320x240 to 320x1 pixels, variation of the frame rate from 5 to 2140 Hz, adjustable integration time from 60 to 500 μs, real-time lock-in detection) allows to analyze the influence of various parameters on the performances. The camera is equipped with a 25mm-objective giving a field of view of 22°x 16°. A two-point Non Uniformity Correction (NUC) has been applied using a blackbody at 5 and 20°C.

Two types of measurements have been made: i) calibration tests of the camera using an extended black-body for intrinsic performances determination, ii) radiation pattern characterization of the EM (Electromagnetic) field generated by a horn at 12 GHz, using the EMIR® (ElectroMagnetic InraRed) technique which consists in measuring the temperature increase distribution of a thin photothermal film illuminated by the EM source, which is representative of the electric field intensity distribution in the plane of the film [1]. The square resistance of the film presently used is 200 Ω.□.

Both space, time and frequency data processing have been tested in these experiments.

3. Intrinsic NETD deduced from calibration using an extend blackbody

Calibration of the camera has been conducted with an extended blackbody. The thermal resolution of the camera is the NEDT, and this parameter is taken as the mean value of the time standard deviation of all pixel deduced from the analysis of a film of 256 images of the blackbody.

Figure 1 presents the space distribution of the pixel time standard deviation for a blackbody at 20°C. The camera works with a window of 320x240 pixels, a frequency of 180 Hz and an integration time of 400 μs. In these conditions the NETD is found to be 19 mK.

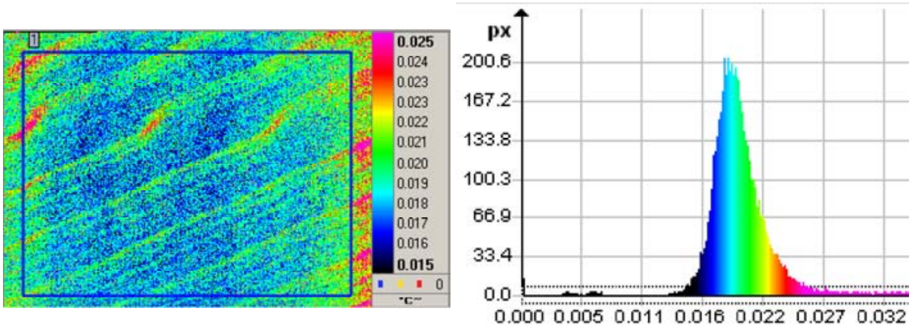

Fig. 1. *Distribution (left) and histogram (right) of the pixel standard deviation calculated from 256 images of an extended blackbody at 20°C, for a field of 320x240 pixels, an image rate of 180 Hz and an integration time of 400 µs. The NETD is assimilated to the mean value of the standard deviation for the full image.*

Table 1 presents the results of NETD measurements made for various windowings for the same integration time. The NETD is found independent of the window size and of the image frequency for a given integration time. On the contrary, for the same window size, the integration time has strong influence on the NETD (see Table 2). The integration time of 400 µs seems to be an optimum and will be used for the electromagnetic measurements using the EMIR technique presented in the second part of the paper.

Table 1. *NETD (influence of windowing)*

Image format	Maximal frequency	Integration time	Measured NETD	Measurement range
320 x 240	185 Hz	400 µs	19 mK	- 40 °C à 40 °C
160 x 120	560 Hz	400 µs	19 mK	- 40 °C à 40 °C
80 x 60	1140 Hz	400 µs	19 mK	- 40 °C à 40 °C
320 x 2	2140 Hz	400 µs	19 mK	- 40 °C à 40 °C

Table 2. *NETD (influence of the integration time)*

Image format	Integration time	Measurement range	NETD
320 x 240	500 µs	-100°C to 5°C	24 mK at 5°C
320 x 240	400 µs	- 40 °C to 40 °C	19 mK at 25°C
320 x 240	200 µs	- 10 °C to 110 °C	39 mK at 25°C
320 x 240	60 µs	50 °C to 290 °C	77 mK at 30°C

4. Enhancement of the performances by time or space accumulation and by lock-in technique

The JADE camera offers the possibility to make time accumulation thanks to the ALTAIR software. Figure 2 presents the mean NETD for the full image obtained for various numbers of accumulated images. Integration time is 400 µs, range –40°C to 40°C, and the blackbody temperature 25°C. An improvement by a factor of near 3 is obtained when accumulating 16 images. The histograms corresponding to these four cases are also given showing that the shape of the distribution is also affected by the process.

Lock-in detection can be used to reduce the NETD as well. With the same configuration (320x240 pixels, integration time of 400 µs, image frequency of 180 Hz) the camera observing the blackbody is synchronized with a generator delivering a signal modulated at 1 Hz. The thermal scene (the blackbody) being not modulated, temperature variations are just due to the blackbody regulation and to residual effects of the natural convection (if any). The results are presented in Figure 3. The improvement is roughly proportional to the square root of the images integrated.

Number of images	Mean NETD (mK)
1	17.09
2	11.45
4	8.77
16	6.55

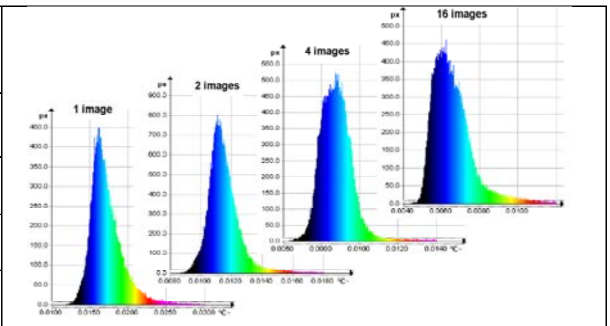

__Fig. 2.__ NETD enhancement by time accumulation and influence on the histogram

Number of images	Measure duration (s)	Mean NETD (mK)
1000	5.56	2.30
2000	11.11	1.58
4000	22.22	1.07

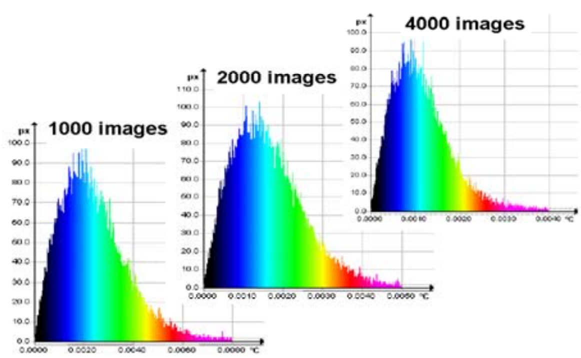

__Fig. 3.__ NETD enhancement by lock-in detection (1 Hz): influence of the number of images accumulated

__Table 3__. NETD enhancement by lock-in detection: influence of the modulation frequency (4000 images accumulated)

Modulation frequency	Mean NETD for the full image
0.5 Hz	1.26 mK
1.0 Hz	1.07 mK
2.0 Hz	0.85 mK

Increasing the modulation frequency improves the results (see Table 3), but, for a given power, the amplitude of the modulated signal decreases proportionally to the modulation frequency, leading to a decrease of the signal-to-noise ratio. Thus the optimum consists to use the minimum frequency which allows suppressing the natural convection effect. This is obtained, for vertical films, with 1 or 2 Hz [1].

5. Radiation pattern of the electric field generated by a X-band horn

5.1. Comparative measurement in CW mode and using lock-in detection

Figure 4a shows radiation patterns of the electromagnetic source obtained in CW regime, with integration of 256 or 10,000 images. The results show very few differences. They are compared to the purely electromagnetic measurement. On the same graph the results obtained with lock-in detection are plotted. The amplitude field is modulated by a square-shaped function and 2,000 images are integrated before calculating the modulus image. With less images integrated (thus with shorter measurement duration), the lock-in results are much better and closer to the electromagnetic measurements. This is due to the incapability of the CW regime and related data processing to eradicate the distortions induced by possible environmental variability (natural convection developing on the photothermal film, film lateral conduction…).

The influence of the number of images processed by lock-in detection in the case of a power of -15 dBm (which corresponds to an incident field on the film of 55 V/m) are presented in Fig. 4b. As already demonstrated with the measurement on blackbody, the increase of the number of images processed (here from 2,000 to 32,000) improves the sensitivity of the detection.

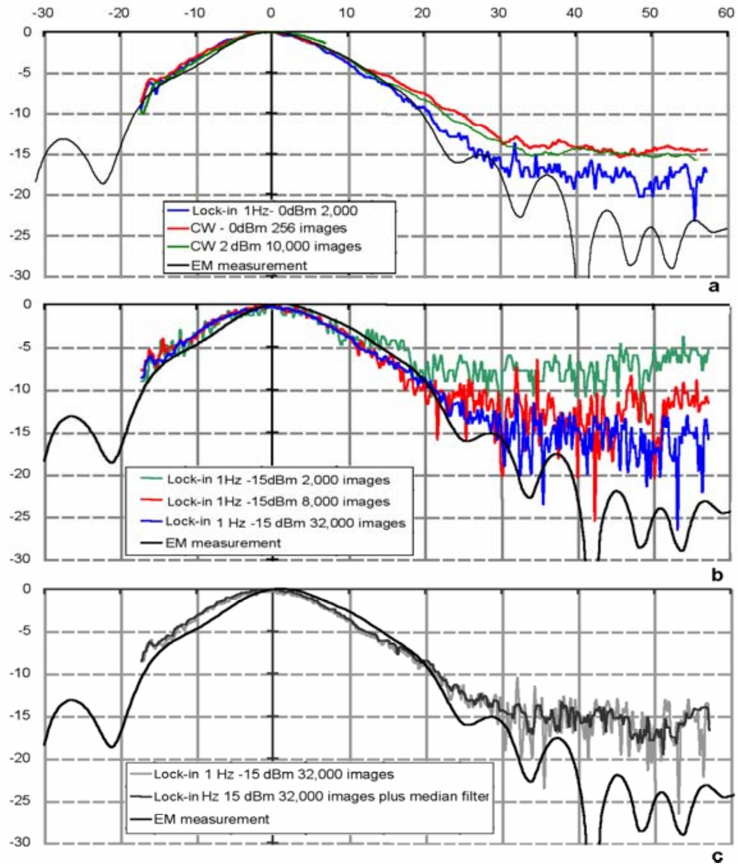

Fig. 4. *Comparison between CW and square-modulated emission and their res-pective time and frequency data processing. a) CW measurements with time accu-mulation and lock-in detection, for a power of 0 dB. b) Influence of the number of images processed by lock-in detection (power: - 15 dBm). c) Mixing space and frequency data processing with square-modulated emission (power: - 15 dBm).*

Figure 4c presents the result of mixing space and frequency data processing with square-modulated emission in the case of a power of -15 dBm. The post-processing (convolution by median-filter) decreases the noise without alteration of the sensitivity. Nevertheless the space resolution is decreased, which is not significant in the present case.

5.2. NETD of EMIR measurement using lock-in detection

The NETD is here assimilated to the space noise standard deviation in a region where the EM field can be considered as null. Practically this value is measured on a line of the image passing by the maximum of the field (see figure 5). The sensitivity or calibration factor, K, is calculated as the ratio of the maximum of temperature increase in the image to the maximum of the measured incident electric field intensity.

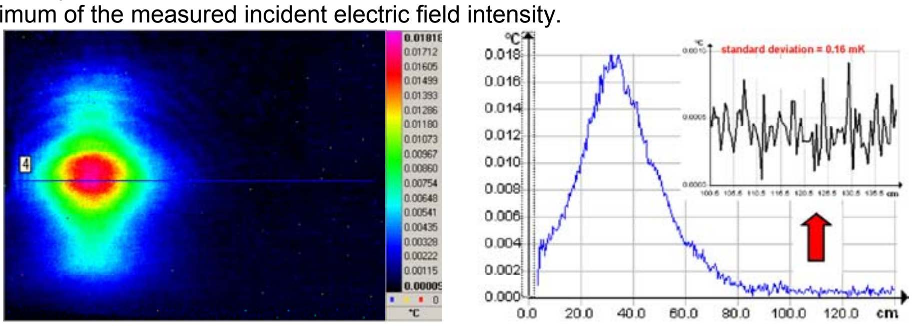

Fig. 5. *NETD evaluation in the EMIR measurement conditions. Left: EMIR lock-in image of the electric field intensity. Right: horizontal profile and part of it used for evaluation of the NETD (assimilated to the space noise standard deviation).*

5.3. Sensitivity, NEEFD and dynamic range of lock-in EMIR measurements

Using the aforementioned procedure, from the EMIR images the following parameters have been deduced (Table 4): i) film sensitivity, K; ii) *NETD*; ii) Noise Equivalent Electric Field Difference, $NEEFD=(NETD/K)^{0.5}$; iii) maximum possible dynamic range, corresponding to measurement conditions given in §4 and to an ambient temperature of 20°C. Two cases are analyzed: no modulation and 256 images accumulated (*f=0*) and amplitude modulation at f=1Hz and 8,000 or 32,000 images accumulated by the real-time lock-in system. Two post-processes are also applied in the last case showing a light improvement of the performances. Accumulating 8,000 images or more allows better performances (in term of *NEEFD* and dynamic range) than working in CW mode with 256 images accumulated, avoiding distortion of the image by convection effects and improving the space resolution [1]. These performances are specific of the film, IR camera and lock-in algorithm used.

***Table 4**. Sensitivity, Noise Equivalent Electric Field Difference and dynamic range of EMIR lock-in technique for the present experimental conditions*

Modulation frequency f (Hz)	Number of accumulated images	Film calibration factor, K (°C/(V/m)^2) x 10^6	Space noise standard deviation (≈ *NETD*) (mK)	*NEEFD* = (NETD/K)$^{0.5}$ (V/m)	Maximum possible dynamic range (dB)
0	256	79	19,6	15.8	26
1	8,000	5.1	0.54	10.5	27
	32,000	5.2	0.16	5.5	33
	32,000 + median filter	5.1	0.11	4.7	34
	32,000 + mean of 4 lines	4.9	0.13	5.1	33

REFERENCES

[1] Balageas, D., Levesque, P., “EMIR: a photothermal tool for electromagne-tic phenomena characterization“, Rev. Générale Thermique, 37, 1998, p 725-739