IMAGE PROCESSING:

AN ENABLER FOR FUTURE EO SYSTEM CONCEPTS

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Klamer Schutte [(1)], Piet B.W. Schwering [(2)]

[(1)] TNO Defence, Security and Safety, P.O. Box 96864, 2509 JG The Hague, The Netherlands, Email: klamer.schutte@tno.nl
[(2)] TNO Defence, Security and Safety, P.O. Box 96864, 2509 JG The Hague, The Netherlands, Email: piet.schwering@tno.nl

ABSTRACT

The current state of the art in electro-optics provides systems with high image quality for associated prices and less expensive systems with subsequent lower performance. This keynote will expound how image processing enables to obtain high quality imagery while utilizing affordable system components. Furthermore, where conventional high-end EO systems are hindered by too much clutter and badly require often unavailable operator assistance, it will be shown that image processing can autonomously generate that information as needed in today's missions.

Noise reduction techniques as implemented by image processing can bring uncooled thermal imagers up to cooled IR system performance levels. Turbulence mitigation techniques can provide long-range surveillance capabilities beyond what is achievable using optical techniques only. Super resolution and image stitching techniques can provide high resolution imagery using modest imagers. In cluttered areas autonomous object detection techniques are essential to dedicate operator attention to the most significant events where the system copes with the complex environment. IED detection is only effective with clutter reduction techniques such as change detection or shape matching; small sea targets filtered from sea-state and coastal backgrounds; subjects shall be discovered with motion-in-motion techniques when manoeuvring in urban areas.

As image processing is a key element to provide high-quality information for affordable prices, it is the enabler for many-sensor systems, including distributed sensing on single vehicles, and integrated views of all group members.

1 INTRODUCTION

Developments in the past in the field of InfraRed (IR) systems have been impressive. In the fifties of the previous century the first InfraRed images have been produced, with commercial cameras following a decade later. Standardization into a commodity started another decade later with the development of the common module. Technology started with a single scanning element, followed by a scanning line array later. Modern camera designs use full Focal Plane Arrays (FPA). A multitude of detector materials is available, including MCT, InSb, VoX and Quantum Well detectors. Currents developments aim at still larger arrays sizes and multiple band sensitivity.

On the other hand, it is observed that the rate of growth in computation capabilities in computer systems is even more impressive. Moore's law still proves valid, today providing standard computer systems to keep up with InfraRed camera systems, and in the future allowing currently impractical complex computer programs to be applied to camera data using modest digital processing systems. This trend leads to opportunities to utilise Image Processing in IR/EO sensors' system design [1].

With the exception of InfraRed Search and Track (IRST) systems, traditional IR/EO system concepts consist of a camera system connected to a display. In today's trends, sensor arrays size increase; environments get more complex [2]; and multi sensor concepts including distributed aperture and networked sensors get more used. These all lead to significant more information displayed for the operator, where at the same time we see trends to reduce operational budgets within defence, thus making less operator time available. Overall these trends are conflicting, and a solution here can be offered by augmenting the common IR/EO system paradigm. When the system autonomously performs clutter rejection and filters out common background events not of interest, significant operator assistance will be provided while retaining the sensitivity provided by the newer camera concepts. Again, Image Processing can provide such capabilities [2], and thus is truly enabling in the future EO system concepts.

2 HIGH QUALITY IMAGERY USING AFFORDABLE SYSTEM COMPONENTS

A significant portion of EO system costs are driven by component costs. High-end IR imaging systems use expensive optics to obtain sharp imagery, with a good SNR, and few aberrations; a large FPA; and a cryogenic cooling mechanism, which over the lifetime of the system even might need replacement. On the other hand, affordable uncooled IR imaging systems have less expensive optics, with smaller apertures and more distortion, and thus less sharpness and a worse SNR. In addition, its FPA is smaller and less sensitive. Also, its effective integration time is longer, resulting in more motion blur.

Yet image processing techniques can effectively counter many of these drawbacks. Noise reduction techniques improves the SNR, image deblurring / image restoration techniques improve sharpness, and super resolution increase resolution. Indeed, the system deterioration due to using affordable uncooled systems can be compensated by existing image processing techniques!

2.1 Noise reduction

Typically InfraRed cameras are hampered by two types of noise: Fixed Pattern Noise (FPN) and Temporal Noise. Fixed Pattern Noise is caused by the non-uniform response of FPA pixel elements across an image, and is quite apparent for many common used IR detector materials. Especially where this non-uniform response is drifting over time, a calibration procedure can only correct the FPN partially. On-line estimation and correction of the FPN can significantly suppress this noise source. The Temporal Noise is a combination of electronics noise, quantum noise, and other time varying noise sources. Image Processing techniques such as temporal averaging (possible after spatial alignment of subsequent frames) or spatial processing can reduce the Temporal Noise.

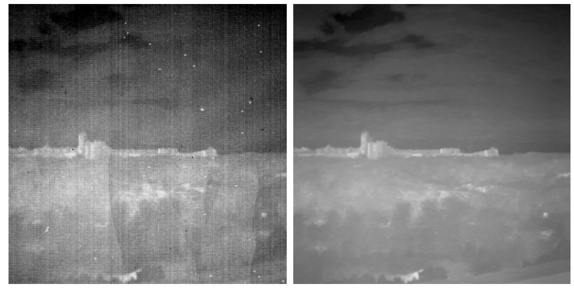

Figure 1: FPN reduction using the TNO Scene Based Non Uniformity Correction applied to a Raytheon HS InSb camera. Left the original, right after FPN and bad pixel removal.

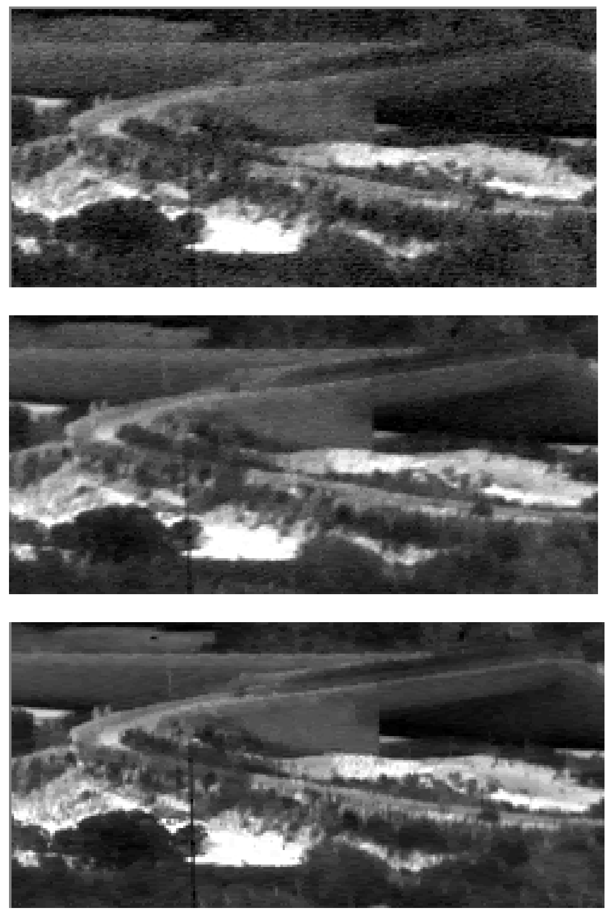

Figure 2: FPN and TN reduction applied to a uncooled LION camera. On top the original, middle after FPN reduction and bottom after temporal noise reduction.

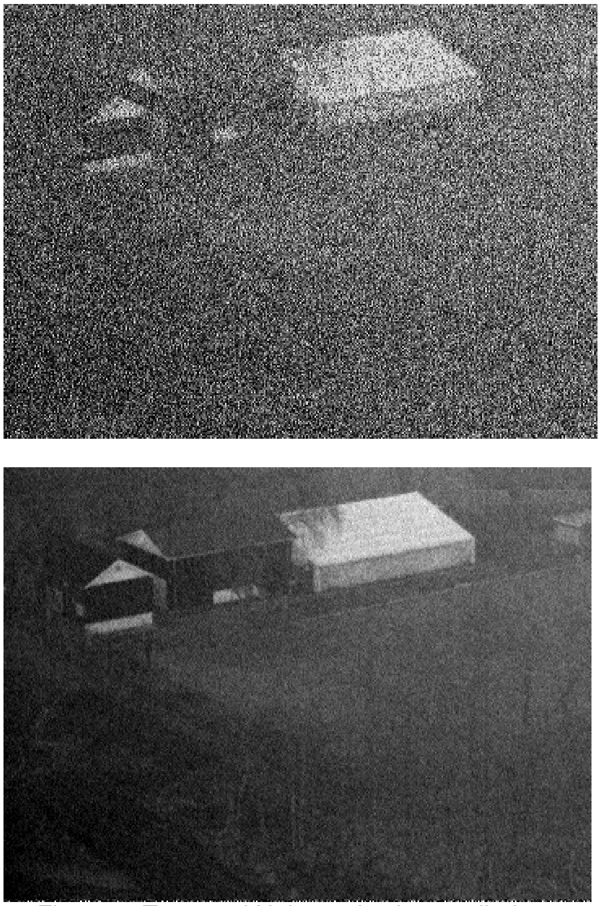

Figure 3: Temporal Noise reduction applied to CCD camera imagery in low light conditions. Above: original; below: after processing

2.2 Sharpness and resolution increase

Spatial resolution of images obtained by camera systems are traditionally characterised by its number of pixels. With the introduction of microscanning techniques it is clear that such a number no longer is the complete answer. Assuming no pixel limit, spatial resolution response is described by the effective Modulation Transfer Function (MTF). Image deblurring / image restoration techniques aim to restore system response to a unity (i.e perfect) MTF, effectively limited by available input SNR and acceptable output SNR. Super resolution reconstruction [3] is an image processing function where sub-pixel shifts between subsequent images are used to increase pixel rate very similar to microscanning. Often super resolution reconstruction is combined with image deblurring, providing a simultaneous increase in both spatial resolution and image sharpness.

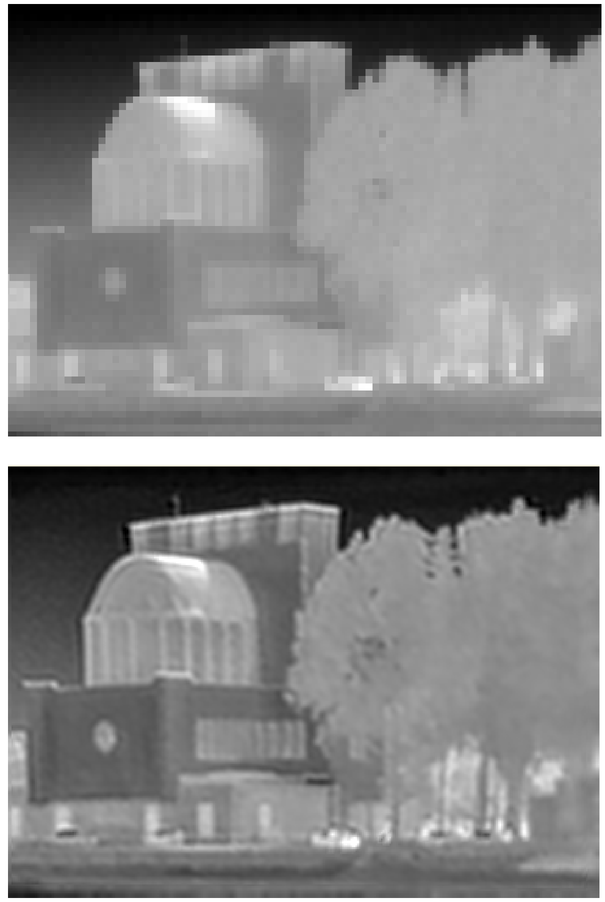

Figure 4: Super Resolution Reconstruction factor 4, together with deblurring applied to a part of a Thales Gatekeeper image, based on uncooled FLIR Photon cameras. Above the original image zoomed a factor 4; below the processed image.

2.3 Image processing chain for uncooled imagers

The chain of image processing to improve the image quality of uncooled IR imagers up to the performance domain otherwise only reached by high-end cooled IR imagers consists of FPN reduction, temporal noise reduction, super resolution reconstruction, and image deblurring. It is the combination of these elements [4] which provides the overall system benefits; the noise reduction improves SNR such that effective image deblurring can be performed; the super resolution reconstruction provides the resolution increase such that image deblurring can work beyond the Nyquist limit; and the image deblurring provides details hidden by the camera MTF and motion blur. Note that different processing elements often are combined in single algorithms, yet all four need to be accounted for to reach the high-end performance domain using affordable uncooled imagers.

3 REDUCING OPERATOR LOAD

In defence and surveillance applications it is the combination of the EO sensor system and its operator which provide the overall system value. In many situations, current EO sensor performance surpasses the capability of a human operator to interpret the image provided. Machine assistance in interpreting the high quality EO data helps here to improve overall system performance.

3.1 Clutter reduction

Even when spatial resolution and signal to noise ratio are sufficient, target discrimination may be hindered by the fact that targets can appear quite similar to background elements. In such cases it is needed to perform in-depth analyses of features such as object shape and its intensity distribution. Especially with clutter dominated scenarios this can be time-consuming, and thus expensive in terms of man power or even unacceptable in time critical applications. The developments towards multi-spectral camera systems can provide help in some but not all scenarios. Image Processing, for example like Aided Target Recognition, can help operators to pay their attention to interesting targets only. In Fig. 5 is depicted that processing can discern wave patterns from an actual target. Fig. 6 shows results where motion information obtained by tracking discriminates benign objects like steady buoys from incoming threads.

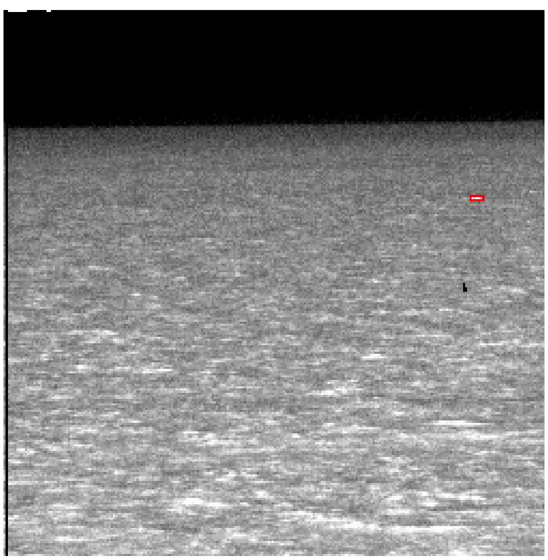

Figure 5: Clutter reduction techniques [5] applied to identify single boat against sea clutter background.

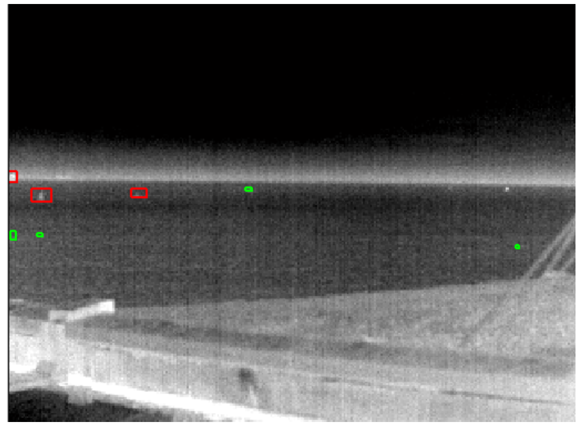

Figure 6. Tracking results [2]. Older tracks in red are detected as potential objects (threats). From left to right a ferry, a buoy and a RHIB. The green tracks are considered friendly.

3.2 Scenario and behaviour analysis

In more complex environments, threats and targets are concealed by more then clutter only. For example, threats are hidden in civilian crowds, and detailed analysis of persons, groups, objects, and their interactions is needed to perform adequate threat analysis. EO sensors are the sensors most capable of providing stand-off discrimination features, yet in current complex operating environments the multitude of possible threats are overwhelming to any operator. Active research is currently pursued to provide significant assistance with these challenges [7].

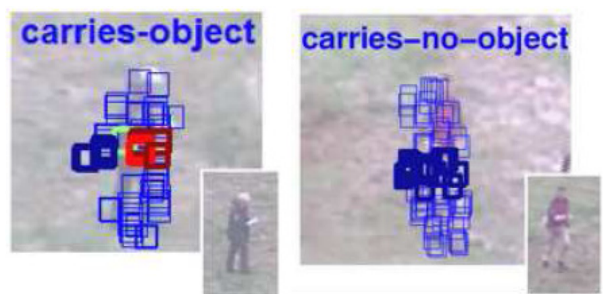

Figure 7. Using spatial features, object classes can be discriminated.

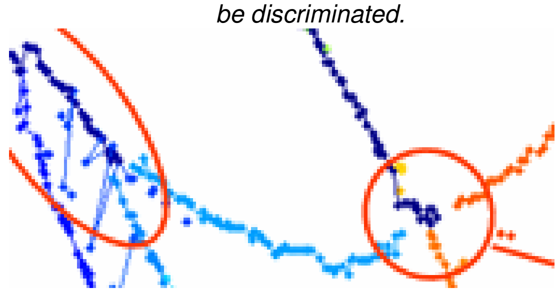

Figure 8. Using trajectory analysis, interactions between persons and groups are identified.

4 PERFORMANCE BEYOND TRADITIONAL LIMITS

4.1 Distortion limited

When the image arrives distorted at the sensor even the best sensor will not perform. Atmospheric effects can provide such disturbances such as turbulence. Camera hardware solutions such as adaptive optics are hard to realize, and will not perform over wide fields of view. Image Processing can correct for such distortions as applied in turbulence compensation [6], speckle imaging or lucky imaging.

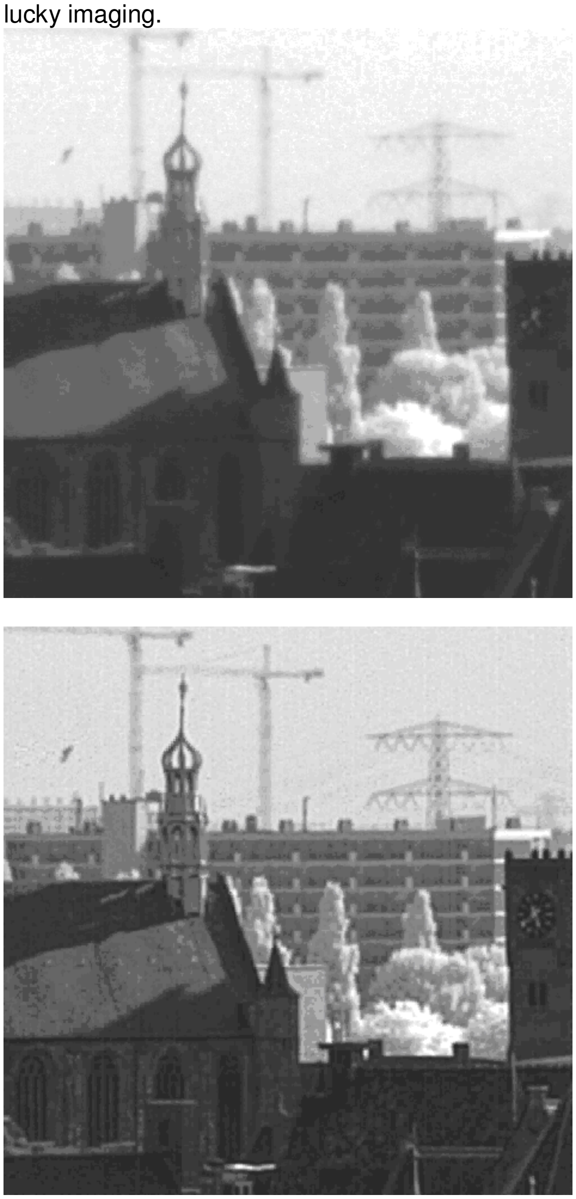

Figure 9: Turbulence compensation applied to long-range visual imagery. Above: original; below: corrected.

4.2 Display limited

With the increasing quality of the camera system the display system in the observation chain can also become limiting. High quality imagers provide images with 12 or more bits; typical displays can simultaneously display up to 64 grey values. This provides a gap between the data offered and that visualized. Image Processing can fill this gap using contrast mapping methods [8].

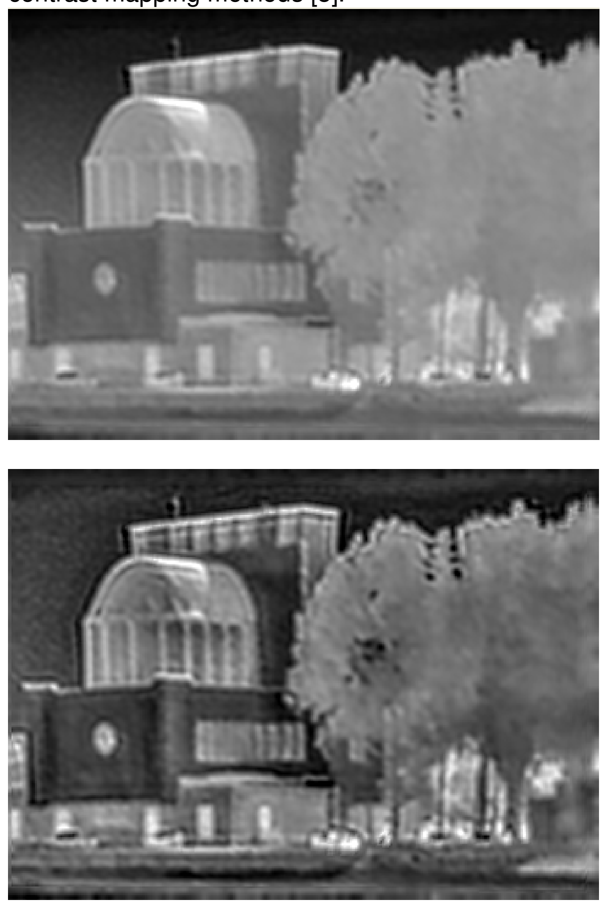

Figure 10: Local Adaptive Contrast Enhancement applied to the result image shown in Fig. 4

5 DISCUSSION

This paper showed several areas where image processing can significantly impact the EO system concepts. Several areas are addressed: improving image quality, hardware cost reduction, operator assistance, and imaging under conditions out of scope of traditional EO system concepts. Initial deployment of techniques as described are currently introduced. Given the rate of innovations in the development of computing technology, it is obvious that incorporating such capabilities to improve EO systems is the way of tomorrow.

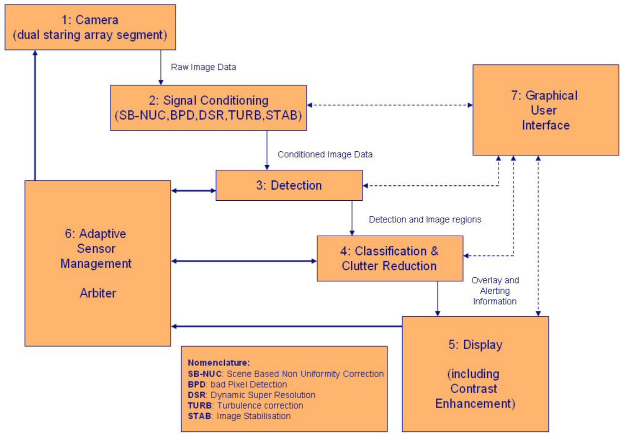

Figure 11. Example block diagram of the algorithms system concept in a surveillance system [6].

6 ACKNOWLEDGEMENTS

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