Fusing Electro-Optic and Infrared Signals for High Resolution Night Images

Xiaopeng Huang[a], Ravi Netravali[b], Hong Man[a] , and Victor Lawrence[a]
[a]Dept. of Electrical and Computer Engineering,
Stevens Institute of Technology, Hoboken, NJ 07030, USA;
[b]Dept. of Electrical Engineering,
Columbia University, New York, NY 10027, USA

ABSTRACT

Electro-optic (EO) images exhibit the properties of high resolution and low noise level, while it is a challenge to distinguish objects at night through infrared (IR) images, especially for objects with a similar temperature. Therefore, we will propose a novel framework of IR image enhancement based on the information (e.g., edge) from EO images, which will result in high resolution IR images and help us distinguish objects at night. Superimposing the detected edge of the EO image onto the corresponding transformed IR image is our principal idea for the proposed framework. In this framework, we will adopt the theoretical point spread function (PSF) proposed by *Russell C. Hardie et al.* for our IR image system, which is contributed by the modulation transfer function (MTF) of a uniform detector array and the incoherent optical transfer function (OTF) of diffraction-limited optics. In addition, we will design an inverse filter in terms of the proposed PSF to conduct the IR image transformation. The framework requires four main steps, which are inverse filter-based IR image transformation, EO image edge detection, registration and superimposing of the obtained image pair. Simulation results will show the superimposed IR images.

Keywords: Theoretical PSF, inverse filtering, EO image edge detection, index superimposing.

1. INTRODUCTION

Infrared (IR) imaging systems depend on thermal contrast between the target and background to generate real time images. These systems create images by utilizing the infrared energy emitted by the objects as a result of their temperature difference with background and emissivity. In addition, the created IR images have low resolution and high noise level. Therefore, how to accurately distinguish objects at night is a challenging topic that has perplexed scientists and engineers for a long time. Fusing IR and electro-optic (EO) images is an effective way to solve this challenge, which combines images from two different sources to obtain a single composite image with extended or enhanced information content. Up to now, scientists have developed many efficient image fusion algorithms, such as the expectation maximization (EM) fusing algorithm [1], the discrete wavelet transform (DWT) fusing algorithm [2], the and Laplacian pyramid fusing algorithm [3]. Additionally, much literature focuses on presenting techniques for estimating a high-resolution IR image via the optimized IR image system [4-5], e.g., with reduced aliasing. However, based on the existing approaches, it is still impossible to accurately distinguish the edges of different objects at night when they have a similar

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temperature and background.

In this paper, we will propose a novel framework to solve this challenging problem. Since EO images exhibit properties of high resolution and low noise level, and there are several sophisticated edge operators for EO images, the principle idea of our proposed framework is to utilize the high resolution property of EO images to help us reconstruct the corresponding edges of different objects in IR images. Assuming we have a pair of EO and IR images, then four necessary steps are required to complete this framework: transform the original IR image into a temperature information-based IR image via the established system point spread function (PSF) and designed inverse filter; detect a clean edge map of the high resolution EO image; register the transformed IR image and the detected clean edge map; superimpose the detected edge map of the EO image onto the transformed IR image. In this framework, we adopt a theoretical PSF for the IR image system, which is comprised of the modulation transfer function (MTF) of a uniform detector array and the incoherent optical transfer function (OTF) of diffraction-limited optics. Final simulation results will show that with the help of the superimposed edge map, we can distinguish between objects in the transformed IR image, and even for any small part of a single object. Above all, the performance of this proposed framework is irrespective of the object's temperature and background. Therefore, this proposed framework can be regarded as a breakthrough of the night time distinguishing of objects.

The remainder of this paper is organized as follows: Section 2 introduces the IR image transformation process in terms of the proposed theoretical PSF and designed inverse filter. Section 3 presents the edge detection of EO images and the related image registration process. The indexing superimposed results are provided in Section 4. Finally, some conclusions and future work are addressed in Section 5.

2. IR IMAGE TRANSFORMATION

2.1 Theoretical PSF

We adopt the *Russell C. Hardie et al.* proposed theoretical PSF [6] for IR image systems, which is contributed by the MTF of a uniform detector array and the incoherent OTF of diffraction-limited optics.

The primary contributor is the finite detector size, and this effect is spatially invariant for a uniform detector array. Let us begin by considering an infrared system with this uniform detector array. We can model the effect of the integration of light intensity over the span of the detectors as a linear convolution operation with a PSF determined by the geometry of a single detector. The second contributor is the optics, and we assume an isoplanatic model for optics.

Let d(x, y) denotes this PSF. Applying the Fourier transform to d(x, y) yields the effective continuous frequency response resulting from the detectors [6]

$$\mathrm{D}(\mathrm{u},\mathrm{v}) = \mathrm{FT}\{\mathrm{d}(\mathrm{x},\mathrm{y})\} \tag{1}$$

where $\mathrm{FT}\{\cdot\}$ stands for the continuous Fourier transform. In addition, define the incoherent OTF of the optics to be $\mathrm{H}_0(\mathrm{u},\mathrm{v})$, where u and v are the horizontal and vertical frequencies measured in cycles/mm. The overall system OTF is given by the product of these, yielding [6]

$$\mathrm{H}(\mathrm{u},\mathrm{v}) = \mathrm{D}(\mathrm{u},\mathrm{v})\mathrm{H}_0(\mathrm{u},\mathrm{v}) \tag{2}$$

Then, the overall continuous system PSF is given by [6]

$$h_c(x,y) = FT^{-1}\{H(u,v)\} \tag{3}$$

where FT^{-1} represents the inverse Fourier transform.

In this paper, we consider a IR system with uniform rectangular detector, which is illustrated in Figure 1, where a and b are the active region dimensions measured in millimeters (mm), T1 and T2 are the horizontal and vertical sample spacings. The shaded areas represent the active region of each detector. In this case, the detector model PSF is given by [7]

$$d(x,y) = \frac{1}{ab}\operatorname{rect}\left(\frac{x}{a},\frac{y}{b}\right) = \begin{cases} 1, & \text{for } \left|\frac{x}{a}\right| < \frac{1}{2} \text{ and } \left|\frac{x}{b}\right| < \frac{1}{2} \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

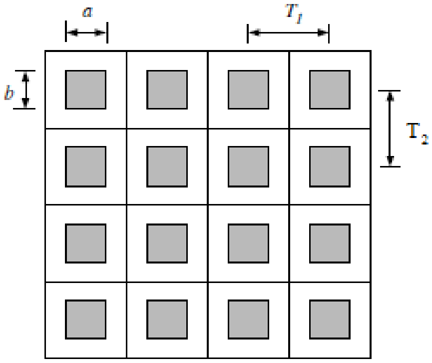


Figure 1. Critical dimensions of the uniform detector array [6].

The corresponding effective continuous frequency response resulting from the detector is given by [6]

$$D(u,v) = \operatorname{sinc}(au,bv) = \frac{\sin(\pi au)\sin(\pi bv)}{\pi^2 aubv} \tag{5}$$

The incoherent OTF of diffraction-limited optics with a circular exit pupil can be found as [6]

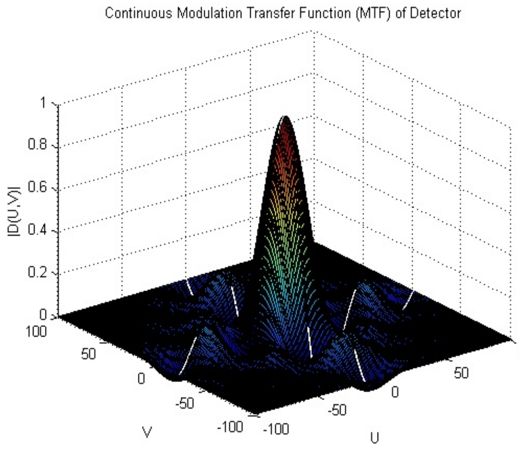
$$H_0(u,v) = \begin{cases} \frac{2}{\pi}\left[\cos^{-1}\left(\frac{\rho}{\rho_c}\right) - \frac{\rho}{\rho_c}\sqrt{1-\left(\frac{\rho}{\rho_c}\right)^2}\right. & \text{for } \rho < \rho_c \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

where $\rho = \sqrt{u^2 + v^2}$. The radial system cutoff frequency ρ_c is given by [6]

$$\rho_c = \frac{1}{\lambda f/\#} \tag{7}$$

where f/# is the f-number of the optics and λ is the wavelength of light considered. Since the cutoff frequency of the optics $H_0\,(u,v)$ is ρ_c , so is also the cutoff frequency of the overall IR system's OTF.

We consider a particular IR imaging system as an example, the typical syste]m considered is the forward looking infrared (FLIR) imager. This systems has square detectors of size a=b=.040mm, the imager is equipped with 100mm $f/3$ optics, the center wavelength =.004mm and the cutoff frequency 83.3 cycles/mm are used for the OTF calculation. Figure 2(a) shows the effective MTF of the detectors, |D (u, v)|, and figure 2(b) shows the diffraction-limited OTF for the optics, H (u, v). The overall system MTF is shown in Figure 2(c), and the continuous system PSF is shown in figure 2(d).



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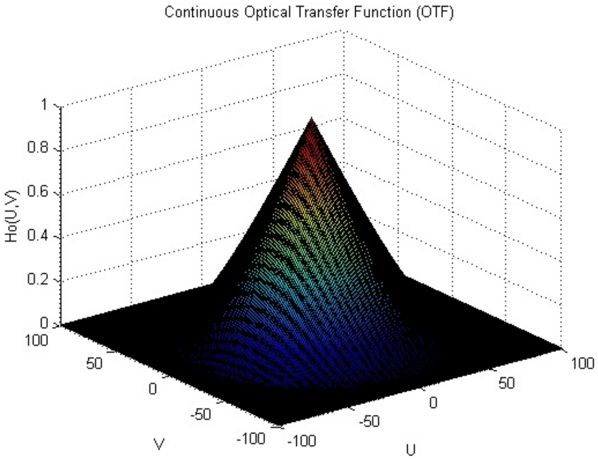
(a)



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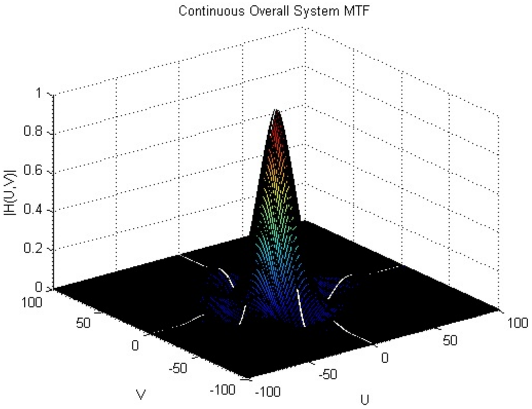
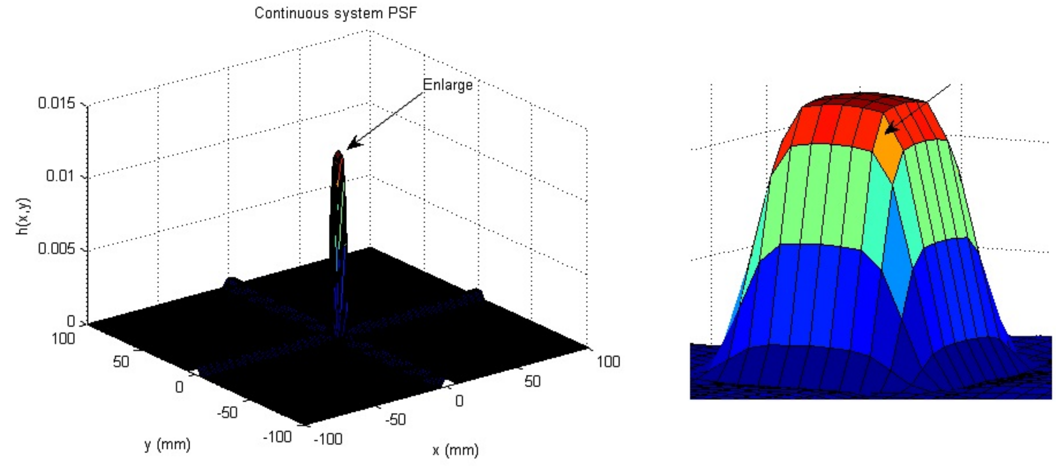


(c)



(d)

Figure 2. (a) Effective MTF of the detectors in the FLIR imagers (b) diffraction-limited OTF of the optics (c) overall system MTF (d) overall continuous system PSF (right side figure is the enlarged PSF).

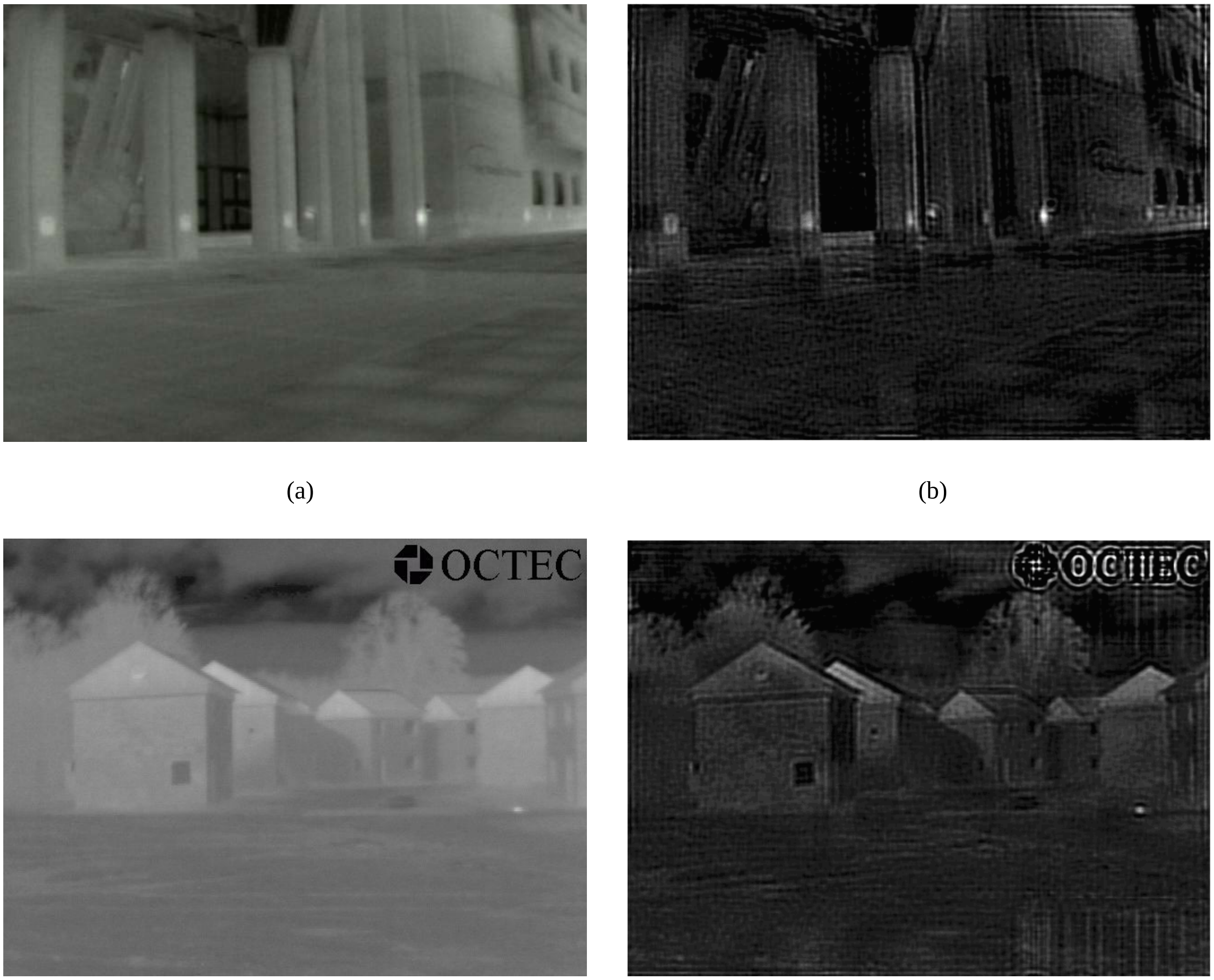
2.2 Inverse filtering and IR image transformation

Usually direct inverse filtering is the simplest approach we can take to restoring a degraded image, which ignores the noise term in the model and forms an estimator in the form of [8]

$$\hat{\mathrm{F}}\,(\mathrm{u},\mathrm{v}) = \frac{\mathrm{G}\,(\mathrm{u},\mathrm{v})}{\mathrm{H}\,(\mathrm{u},\mathrm{v})} \tag{8}$$

where G (u, v) is the degraded image, and H (u, v) is the system PSF. Then, we obtain the corresponding estimate of the image by taking the inverse Fourier transform of $\hat{\mathrm{F}}\,(\mathrm{u},\mathrm{v})$.

In this paper, we assume the proposed theoretical PSF to be H (u, v) in the designed inverse filter. Let original IR image pass through the designed inverse filter, then we can obtain a transformed IR image with temperature information of the objects. Figure 3 shows two IR image transformation examples in terms of the designed inverse filter.



(a) (b)

(c) (d)

Figure 3. (a) Original IR Image 1, (b) transformed IR Image 1 via the inverse filter, (c) original IR Image 2, (d) transformed IR Image 2 via the inverse filter.

3. EO IMAGE EDGE DECTION AND REGISTRATION

3.1 EO image edge detection

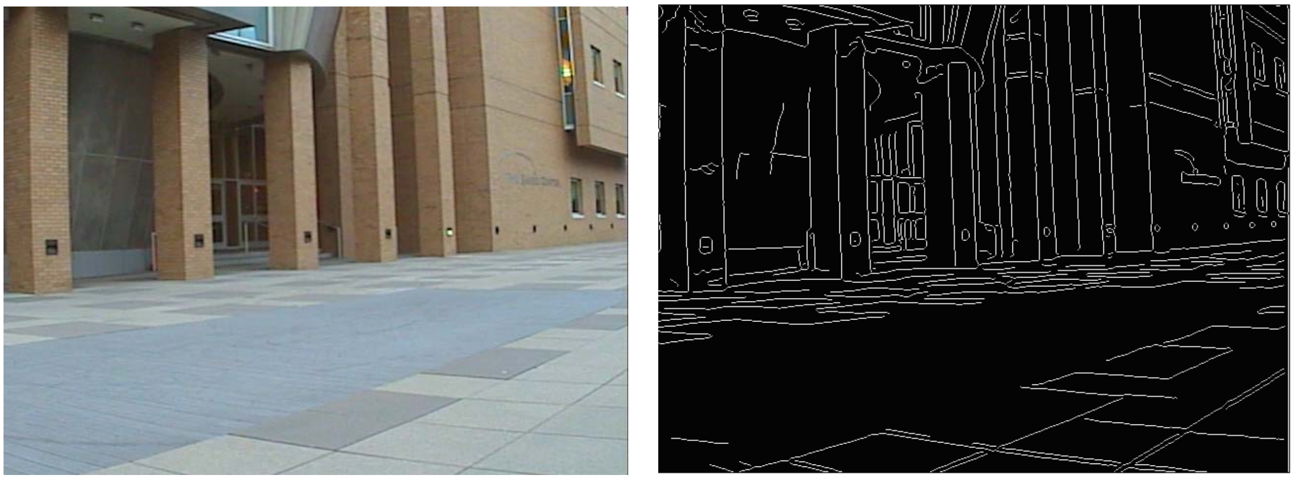
EO image edge detection refers to the process of identifying and locating sharp discontinuities in an image. The discontinuities are abrupt changes in pixel intensity which characterize boundaries of objects in a scene. By far, edge detection is the most common approach for detecting meaningful discontinuities in intensity values. There are many edge operators to perform edge detection, e.g., Sobel, Prewitt, Roberts, Laplacian of a Gaussian (LoG), Zero crossings and Canny. However, the majority of different operators may be grouped into two categories: one is the gradient based edge detection, which detects the edges by looking for the maximum and minimum in the first derivative of the image; the other is Laplacian based edge detection, which searches for zero crossings in the second derivative of the image to find edges, an edge has the one-dimensional shape of a ramp and calculating the derivative of the image can highlight its location.

The Canny edge detection algorithm [9] is known as the optimal edge detector. The detail description of the Canny edge detector can be found in [8], where the syntax for the Canny edge detector in Matlab is

$$[g, t] = \text{edge}(f, \text{'canny'}, T, \text{sigma}) \tag{9}$$

Where f is the original EO image, T is a vector, T = [T1, T2], containing the two thresholds of the preceding procedure, and sigma is the standard deviation of the smoothing filter. We can change these parameters so as to produce clean edge maps.

Figure 4 shows two edge detection results via the Canny edge operator, where sigma is chosen to be the default value 1. Seen from the obtained results, we can find out that the detected edge of each EO image is clean enough, and it covers all essential information in the original EO image.



(a) (b)

(c) (d)

Figure 4. (a) Original EO Image 1, (b) detected edge of EO Image 1 (T1= 0.04, T2=0.09), (c) original EO Image 2 (public image), (d) detected edge of EO Image 2 (T1= 0.035, T2=0.082).

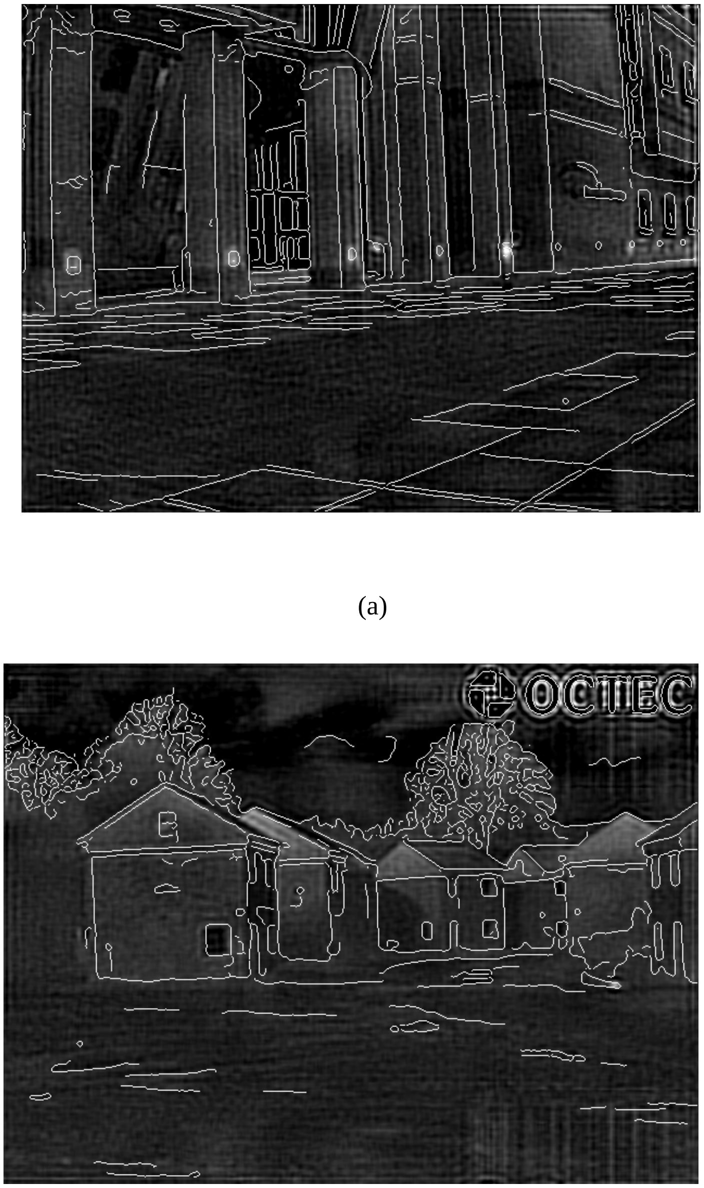
3.2 Image pair registration

Image registration methods seek to align two or more images of the same scene. Image registration methods generally consist of the following basic steps: detect features, match corresponding features, infer geometric transformation, and use the geometric transformation to align one image with the other. In this paper, we adopt the `cp2tform` function from the Matlab image processing toolbox to do the manual-based image pair registration. As for the more complicated image registration processes (e.g., image registration involves shift, rotation and transformation), they are beyond our paper's scope.

4. INDEX SUPERIMPOSING RESULTS

The last step of our proposed framework is to superimpose the detected edge of the EO image onto the transformed IR image. Typically, there are two basic ways to superimpose images: One involves using transparency to overlay images, and the other involves indexing the image data to replace pixels. Here, we adopt the indexing superimposing approach to achieve our purpose.

Figure 5 shows two superimposed examples. Generally speaking, based on our results, we can distinguish objects accurately at night via the clean edge of the EO image superimposed on the corresponding transformed IR image, especially for objects with a similar temperature, which is extremely difficult or even impossible based on traditional object distinguishing approaches.



(a)

(b)

Figure 5. (a) Indexing superimposed result of the transformed IR Image 1, (b) indexing superimposed result of the transformed IR Image 2.

5. CONCLUSIONS AND FUTURE WORK

Since the imaging formation principle of IR images is based on the temperature of objects, and IR images have lower resolution and higher noise level compared with those of EO images. Therefore, it is a challenge to accurately distinguish objects at night, especially when objects with a similar temperature. Unlike traditional image fusing approaches, we proposed a novel framework to achieve this goal based on the help of EO images captured in the daytime. To be specific, we superimposed the detected clean edge of the EO image onto the corresponding transformed IR image. Simulation results in Part 4 showed that we could clearly distinguish objects at night regardless of their temperature and even for a small part of a single object. However, the results of the proposed novel framework are preliminary, we still need to improve the performance from two aspects of our framework: IR image transformation and edge superimposing.

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