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Reproducing kernel hilbert space based single infrared image super resolution

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HIGHLIGHTS

- Infrared image are analyzed by reflective, cooled emissive and uncooled emissive.
- Model by spline based reproducing kernel hilbert space and heaviside function.
- The robust model is applicable to all infrared images.
- The small root mean-square-error of reconstructed high resolution images.

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ABSTRACT

The spatial resolution of Infrared (IR) images is limited by lens optical diffraction, sensor array pitch size and pixel dimension. In this work, a robust model is proposed to reconstruct high resolution infrared image via a single low resolution sampling, where the image features are discussed and classified as reflective, cooled emissive and uncooled emissive based on infrared irradiation source. A spline based reproducing kernel hilbert space and approximative heaviside function are deployed to model smooth part and edge component of image respectively. By adjusting the parameters of heaviside function, the proposed model can enhance distinct part of images. The experimental results show that the model is applicable on both reflective and emissive low resolution infrared images to improve thermal contrast. The overall outcome produces a high resolution IR image, which makes IR camera better measurement accuracy and observes more details at long distance.

1. Introduction

Infrared technology plays an important role in exploring beyond eye invisible imaging, which is connected with military needs [1], civilian application [2], scientific research [3] and medical treatment as traumatic knee injuries [4], cancer diagnostics [5]. As a result, it is estimated that the global infrared imaging market will reach to $8450 million by 2020 [6] and the top players in the market are competing to penetrate the market by providing low cost, high resolution compact systems. The most critical component in infrared imaging system is sensor which determines the overall system performance. The sensing criteria can be divided as thermal and photon infrared sensing [7]. The former sensitive element's temperature varies because of the IR absorption, which generates an electrical signal change. The latter photon infrared detectors absorb infrared radiation and induce electrons into a higher energy level which contributes to electric signal. The photon quantum detectors are very fast response (ns–μs) compared to thermal IR detector (ms) [8]. Although the cost, speed, sensitivity and temperature range are key features for infrared imaging system, the spatial resolution determines the fine detail and clarity, the temperature measurement accuracy, imaging distance and object size [9]. There are at least three factors hindering high resolution IR Focal Plane Array (FPA): optical diffraction, readout circuit (ROIC) mismatch and detector non-uniformity [10]. In the visible spectrum, silicon can be both used for sensing material and readout electronics. However, infrared FPA is fabricated by $Hg_{1-x}Cd_xTe$, $Pb_{1-x}Sn_xTe$, InSb, AlGaAs, etc. [11]. In order for integration, the FPA and ROIC are separate in hybrid array construction,

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where two arrays are carefully aligned and pressed together using indium as electrical connection [12]. For the flip-chip hybrid technology, the chip size is limited on order of 20 mm^2 due to thermal mismatch between FPA and ROIC [9]. Although there is nonuniformity correction based on-chip processing [13] to reduce the static spatial pattern noise and alternative epitaxy technology with sapphire to overcome thermal mismatch problem, the hardware cost is still unacceptable high.

From signal processing perspective, obtaining High Resolution (HR) image from observed Low Resolution (LR) image/images is an interpolation problem which expands low frequency sampling into high bandwidth [14]. Table 1 lists the super resolution method in visible spectrum. The most straightforward is nonuniform interpolation [15], which is performed successively by motion estimation, interpolation and restoration. In [16], the aliasing between LR and HR signals fourier transformation is made to reconstruct super resolution image in frequency domain. The model based approaches including regularized reconstruction, deterministic [17], and stochastic [18] method are also reported, though all are high computational cost. Single LR image based super resolution (SR) algorithm is more competitive compared to multiple LR images method due to easy system integration. The nearest neighbor [19] and bicubic interpolation [20] are widely used in imaging tools. The machine learning based super resolution needs large training set to output a better result. Meanwhile, the novel approaches focus on compressive sensing [21] and sparse representations [22]23 to improve image spatial resolution.

The infrared image super resolution is more challenging and essential due to high cost manufacturing process for large sensor array in MWIR and LWIR wavelength. The earlier IR super resolution methods were coming from visible spectrum techniques [24,25]. Besides, The sparse representation was also applied on infrared image super resolution which made the high resolution patches share the same representation as low resolution patches [23]. The non-sampled contourlet transform was proposed to improve infrared image quality based on low pass subband and bandpass subband images [26]. The regularized technique was adopted on infrared images super resolution by ℓ_1-norm and total variation norm [27]. The human vision processing mechanism together with vision lateral inhibition was utilized to enhance the image contrast between object and background [28]. Moreover, the correlation of an infrared image and its corresponding visible image were suggested to improve resolution, in which the visible image generated edge maps [29]. In overall, most approaches were directly borrowed from visible image processing which didn't consider the features of infrared image.

In this paper, a single image based super resolution method is proposed to reconstruct high resolution IR image, which is robust on near IR, SWIR, MWIR and LWIR images. The distinct features of IR image are classified as reflective, cooled emissive and uncooled emissive by sensing mechanism. Section 2 briefly describes the characteristic of IR images from reflection and emission. Section 3 introduces the low resolution observation model and how to build mathematical model using Reproducing Kernel Hilbert Space (RKHS) and heaviside function. Section 4 discusses the algorithm in details. The experimental results and conclusions are depicted in Section 5 and Section 6.

Table 2
IR irradiation in night scene.

Wavelength	Type	Category	IR camera application
0.72–1.4	Reflective	Near IR	Night vision goggles
1.4–3	Reflective/emissive	SWIR	Night vision camcorder
3–8	Emissive	MWIR	MWIR Camera
8–14	Emissive	LWIR	LWIR Camera

2. Characterization of IR image

The IR images measure infrared irradiation and its distributions. There are two IR sources for imaging, one is internal emissivity due to Planck's law [7] and another is external reflection similar as visible light. In other words, they are working in passive mode, which detects the thermal radiation given off by a warm object without the need for illumination, or active mode, which uses an invisible infrared source to illuminate the scene. Table 2 compares the wavelength, working type and its applications. The reflective and emissive are corresponding to active mode and passive mode respectively.

2.1. Reflective IR image

In natural, there are a lot of IR sources, as sunlight and airglow at night, man-made LED and laser IR illuminators, which irradiate near IR about 750 nm to 1 μm in wavelength. The active/reflective infrared imaging system behaves exactly similar as visible SLR camera, which expresses the shape of object and its infrared reflectance. However, there is a considerable difference between visible and near IR images. The near IR reflectivity is quite different from visible for most of materials. As shown in Fig. 1, the vegetation and dry bare soil have higher reflectivity in near IR than visible while water has all absorption in near IR band. In overall, the near IR images have a higher contrast for outside imaging [30]. Fig. 2 shows the difference between visible (right) and near IR (left) reflection image on same scene, in which the brightness and contrast of left (near IR) images are higher than right (visible) in visual. The sharpness and contrast are more important and dominant features on near IR images.

2.2. Emissive IR image

The reflective IR imager limits the application due to IR source needed. However, the image acquisition in passive/emissive mode, also referred to thermal infrared camera, consists of another huge number of applications. It measures the emissivity and temperature of objective target comprehensively. The thermal infrared spectrum spreads from MWIR to LWIR, VLWR for nature scene. From photodetector perspective, there are narrowband cooled

Table 1
Visible spectrum image super-resolution.

Method	Observed LR images	Characteristics
Nonuniform interpolation	Multiple	Low computational load and real time application possible
Frequency domain	Multiple	Theoretical simplicity, convenient for parallel implementation
Regularized reconstruction	Multiple	Inversion of ill-posed problem
Deterministic approach	Multiple	Minimize the amount of high pass energy in the restore image
Stochastic	Multiple	Quadratic potential function, solution become oversmoothed
Nearest-neighbor	Single	Fast but jaggy effect
Bicubic interpolation	Single	Blur effect
Learning based	Single	Training data set, computational expensive