Image Distortion and Non-Uniformity Correction for Transient Imaging Multi-spectrum Thermometry

CAI Jing, ZHANG Xuecong, YANG Yongjun, MENG Su
Changcheng Institute of Metrology & Measurement, Beijing, China

Email: xuecong.zhang@foxmail.com

Abstract: This thesis focuses on the research of multi-spectrum thermometry image distortion and non-uniformity correction based on the characteristic of single CCD transient imaging multi-spectrum thermometry. A distortion correction based on Zhang calibration is used to rectify the lens distortion. A non-uniformity correction combined two-point calibration with neural network is carried out to rectify the non-uniform images. Compare the images before and after correction, the distortion calibration method used in this thesis can decrease the error between the field image and the target location. The comparison of the images before and after non-uniformity correction illustrates that the non-uniformity correction used in this thesis can reduce the temperature measurement error caused by CCD pixel conformance differences observably.

1. Introduction
With the development of the infrared thermal technology, thermal imager is of great significance to measure temperature distribution under hot surfaces. Owing to its single band measurement, target emissivity has great impact on temperature measurement results. A comparatively new technique of using the multi-spectrum thermometry is carried out. Single CCD transient imaging multi-spectrum thermometry uses optical imaging modality to separate near-infrared radiation into per band multiple channels, and image them on near-infrared focal plane array detectors separately. This method only uses one CCD to ensure low costs, and enables several wavebands to image simultaneously to deal with the temperature measurement of dynamic target. This thesis focuses on multi-spectrum infrared image method to increase the accuracy of temperature distribution measurement according to the structure of transient imaging leans and the zoning imaging characteristic of single CCD.

2. Transient Imaging Multi-spectrum Thermometry
The waveband of transient imaging multi-spectrum thermometry used in this thesis is near-infrared band within the limits of 1.0μm ~ 1.7μm. It is distributed into four channels and the images in different wavebands are imaged on four quadrants in near-infrared CCD. Based on the multi-spectrum theory, the target temperature of each pixel in these quadrants can be calculated by fusing the images in four quadrants and finally form the temperature distribution images which can help display the target temperature distribution intuitively.

The schematic diagram of transient imaging multi-spectrum thermometry is shown in figure 1. Firstly, the target goes through the front objective lens and images on the rectangular field diagram. The field diagram is used to limit imaging range and prevent aliasing among different wavebands in the detector. Then, the collimating lens transform the beam into parallel rays. After going through a 2*2 lens array, the images are shown in four quadrants on the detector. Finally, utilize the filter coating in different wavebands plated on lens array, four channels are formed eventually.
Infrared image processing is combined with two parts: distortion rectifying and non-uniformity rectifying. Distortion is mainly caused by the imperfect imaging, which can lead to a non-corresponding of the temperature distribution and the spatial position. Heterogeneity arises primarily from the pixel response non-uniformity of the detector and the same radiant energy image in different pixel will cause different outcomes.

The multi-spectrum temperature calculating principle is to figure out the target temperature according to radiation energy ratio under several spectral channels. It is demanded that each pixel corresponded to their spectral channel must reflect the same location of real target in transient imaging multi-spectrum thermometry. Otherwise these pixels will receive radiation energy in different temperature because of maldistribution of target temperature which will made the target temperature unable to be calculated. Because the objective lens of near-infrared imaging covers a relatively wide waveband range, optical aberrations like color aberration and spherical aberration can affect the image quality in different channel respectively to a different extent. So the distortion rectification corresponding to the images in each channel is ought to be taken to ensure a one-to-one correspondence between the pixel in each channel and the target location. Meanwhile, detectors adopt the near-infrared focal plane array, which result in response differences between each pixel as well as the non-equivalence between the output ratio and the energy received. It is essential to take a non-uniformity correction to these images to ensure energy ratio reception corresponded to their pixel in each channel and figure out the correct temperature.

3. Distortion Correction based on Zhang Calibration

For calibration of optical system, traditional precision angle measurement method or precision length measurement method can be used to take the distortion measurement of optical system. Computer vision is also available to calibrate optical system. These methods mentioned above all require calibration board which determine an accurate geometric position should be concerned to influence the calibration results directly. An infrared calibration plate is ought to be an infrared objective which can ensure the accuracy of geometric position as well as a precise and comprehensive object plane provided to the distortion measurement of infrared imaging system.

At this stage, a mature and widely used image distortion correction technology is provided by Zhengyou Zhang. The main idea is to get the distortion factor and then make the opposite conversion to eliminate the distortion.

4. A Non-uniformity Rectify combined Two-Point Calibration with Neural Network

In Infrared Focal Plane Array, the response non-uniformity which is the same as pixel consistency, and the blend pixel are the main factors to determine the quality of original infrared images. Response non-uniformity can cause fixed-pattern noise while blend pixel can lead to bright spots or dark spots in infrared images. Therefore, non-uniformity corrective and blend pixel compensation are essential in thermal imaging system.

The non-uniformity rectification usually takes two-points calibration, using the black body in two different temperatures to detect offset and correction coefficient of each pixel. Because of the
nonlinearity of real detector response, an error must be existed based on two-point calibration. The compensation coefficient can also be changed by the effect of environment temperature. To overcome these two drawbacks, a neural network is carried out. A neural network do not need to calibrate infrared focal plane arrays, and the compensation coefficient can continuous update through learning which will reduce the requirement of linearity and stability in pixel photoelectric response. However, long iteration time and low adjusting speed make it difficult to achieve a real-time correction. This thesis combines two-point calibration with neural network to make it available to have fast convergence and a self-adjusting compensation coefficient.

5. Evaluation of image processing

To evaluate the effect of image processing, distortion correction and non-uniformity correction are two evaluation standards. The distortion correction device is shown in figure 2. The light source is got from halogen lamp and irradiated on diffuse plane. Grid-like calibration is allocated between the diffuse plane and the transient imaging system, and the imaging is scanned by transient imaging system carried on distortion correction.

Figure 2. The structure of distortion correction device

Four channels infrared images are shown as figure 3:

Figure 3. Four channels infrared images

The distortions in four channels are inconformity, so it is necessary to rectify each channel respectively. Take the third quadrant as an example, the image before and after rectification is shown as figure 4.
Take a uniform blackbody radiation source with large caliber as an object to verify the rectification result. Figure 5 presents the results of temperature field measurement before and after rectification. It is evident that the uniformity of thermal field figure has improved substantially after non-uniformity rectification. Figure 6 presents the histogram of temperature distribution before and after rectification.

6. Conclusion
This thesis focuses on the research of infrared image treatment of single CCD transient imaging multi-spectrum thermometry. A distortion correction based on Zhang calibration is used to rectify the lens distortion. A non-uniformity rectification combined two-point calibration with neural network is carried out to rectify the non-uniform images. After an image processing, the distortion and uniformity of thermal field has improved substantially as well as thermometry accuracy and spatial accuracy.

7. References
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