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Improvement of Infrared Image Based on Directional Anisotropic Wavelet Transform

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Abstract

In this paper, for infrared images, the image enhancement technique based on wavelet transform is studied, which is a process that automatically apply different filtering coefficient toward different directions. The algorithm, including the application of nonlinear anisotropic diffusion, is experienced to the enhancement of infrared images. For directional filtering, the structural feature at each pixel is analyzed by the eigen-analysis. If the analysis shows that the pixel belongs to the edge region, we then perform directional smoothing along the tangential direction of the edge to improve its continuity, while directional sharpening along the normal direction to enhance the contrast. Meanwhile, the noise in the homogeneous region has been reduced notably by applying the appropriate wavelet coefficient. The algorithm is so effective that it reduces the noise while enhancing the edge sharpness at the same time. The quantitative measurements along with the visual inspection were also compared and results showed the algorithm based on wavelet transform has the ability in enhancing the infrared image. The proposed algorithm is compared to the other regular noise-reducing algorithms. The experimental results show that the proposed algorithm considerably improves the infrared image quality without causing any noticeable artifacts. Out of the algorithms compared, our algorithm demonstrated the best performance.

Intridiction

Infrared light lies between the visible and microwave portions of the electromagnetic spectrum. It is part of our daily life but we seldom notice it. It is invisible to human eyes, but people can feel it as heat. Its wavelength ranges from 0.74μm to 300μm, corresponding to a frequency range of approximately 1 to 400 THz, and include most of the thermal radiation emitted by objects near room temperature. Microscopically, IR light is typically emitted or absorbed by molecules when they change their rotational-vibrational movements. Images received through various infrared (IR) devices in many applications are distorted due to the atmospheric aberration mainly because of atmospheric variations and aerosol turbulence [1].

Infrared imaging, also called thermal imaging, has become increasing popular because it is safe, nondestructive, relatively inexpensive, and provides a long-range detection. It is is used extensively for military and civilian purposes. Military applications include target acquisition, surveillance, night vision, homing and tracking. Civilian uses include thermal efficiency analysis, remote temperature sensing, short-ranged wireless communication, spectroscopy, medical imaging and weather forecasting[2]. In last century, the expensive manufacture costs had prevented it from being widely used. In the past 20 years, uncooled detectors have given new opportunities in the IR field of applications by picking up rather than completing or developing dormant applications. Compared to cooled technology, the uncooled detector offers many interesting advantages: high reliability, lower cost, no need to conjugate the optical pupil stop with the cold shield (additional degree of freedom for the optical designer), whereas the performance is high enough for a lot of applications where the targeting range is relatively close to the sensor (typical range around 1km) such as thermography application, automotive, military: thermal weapon sight, low altitude UAV sensor [3]. For such applications, FLIR and ULIS have developed many types of uncooled detectors. In this paper, we use images generated by ULIS 384 x 288 / 25μm detector as examples. The uncooled sensor has been embedded in the following infrared camera module as shown in figure 1. This module has shutter installed for calibration and use Altera Cyclone V FPGA to process the data from infrared sensor.

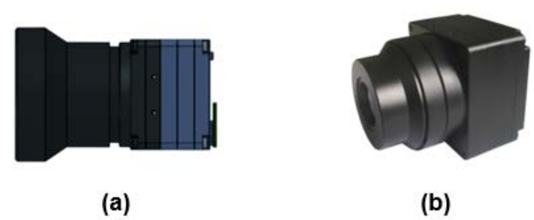


Figure 1. *The infrared camera module used for image extraction (a) Design of the module (b) Appearance of the module with athermalized lens(f=19mm, F=0.9)*

However, the main problem of infrared images is the poor quality, mainly caused by the low contrast appearance of the monitored objects. Compared to the visible light, the infrared signal is so weak that it is comparable to the noise level. Image enhancement is a very important field in image processing. Enhancement targets at improving the visual quality of an image by sharpening edges and smoothing flat areas. Several researchers have studied this field using different approaches such as simple filtering, adaptive filtering, wavelet denoising, homomorphic enhancement and etc., [4][5][6]. All these approaches concentrate on reinforcing the details of the image to be enhanced. Infrared image processing is a new field emerging for the evolution of night vision cameras. It also has applications in thermal medical imaging [4,5]. This evolution of night vision cameras has encouraged the research in infrared image enhancement for information extraction [7].

The enhancement of infrared images is kind of different from traditional image enhancement in dealing with the large flat areas and the small details. So, we separate the details in different sub-bands and processing each sub-band in our proposed approach. As we mentioned above, noise is comparable to signal in infrared images, it is difficult to separate them directly with regular spatial information. However, wavelet transform has characterized their difference in frequency and showed different details in sub-bands. Therefore, the separation in wavelet sub-bands will indentify the noise much more accurately and remove it to improve the image quality with wavelet reconstruction. Considering that the additive wavelet transform is a very effective in image decomposition, the infrared image is decomposed using the additive wavelet transform, and the details can be separated into the higher frequency subbands. Also, we use the enhancement algorithm for transforming these details to approximation and detailed components. Then, the detailed components are amplified showing the details. In the end, a wavelet reconstruction process is performed to get an enhanced infrared image with more details [9].

Many methods [9,10,11,12] have been proposed for the noise reduction, such as temporal averaging, median filtering, and Wiener filtering. Temporal averaging uses multiple images that are obtained over a time period to increase the signal-to-noise ratio (SNR). This method is efficient for reducing noise but often leads to the loss of small details due to blurring. Median filtering is performed by taking the magnitude of all of the vectors within a mask and sorted according to the magnitudes. It can alleviate the noise without obviously reducing the sharpness of the image and edge preserving nature. However, it still has a limit to keep fine details in an image. Wiener filtering converts multiplicative noise into additive noise and applies Wiener low-pass filtering, but is meaningful only when additive noise is present. Bilateral filtering combines domain and range filtering, exhibiting superior properties in comparison to the smoothing filters routinely applied for noise reduction. However, its coefficients rely heavily on the intensities of the neighboring pixel instead of the entire region, which could cause blurred borders. In order to reduce noise while keeping edges, anisotropic diffusion based filtering methods have been proposed. One of these methods is the Gaussian smoothing based on nonlinear coherent diffusion (NCD) model [13]. The NCD model can efficiently detect edge pixel and its orientation. But this method is a reduce noise while keeping edges, therefore difficult to characterized the edge thickness and sometimes the detected edge orientation may not represent global characteristics.

Proposed Method

The conventional wavelet based algorithms usually perform the image enhancement by adjusting the magnitude of wavelet coefficients. Our algorithm is based on a multi-scale wavelet transform method which decomposes an image into sub-bands using the filtering approach [14][15][16] in several consecutive stages. We perform directional filtering and noise reduction for every stage. Fig. 1 shows the overall block diagram of the proposed algorithm. The wavelet transform decomposes image into approximation part and detail part, the approximation part remove the noise as well as the edge detail, while the detail part magnifies the edge details and only keep those detail coefficient by setting threshold for different levels. The following is the decomposition low pass filter that we have used in this method [16].

$$H = \frac{1}{256}\begin{pmatrix} 1 & 4 & 8 & 4 & 1 \\ 4 & 16 & 32 & 16 & 4 \\ 8 & 32 & 64 & 32 & 8 \\ 4 & 16 & 32 & 16 & 4 \\ 1 & 4 & 8 & 4 & 1 \end{pmatrix} \quad (1)$$

In addition, for every detail part, we process in two stages: the analysis stage and filtering stage. During the analysis stage, edges and noise are determined, and edge orientations are analyzed at each resolution scale during the image decomposition. In the wavelet domain, we analyze the structural information to detect edges and separate the noise from the real edge details. During the filtering stage, the noise reduction procedure is applied toward flat regions, which are identified in the analysis stages. Also, the edge reinforcement procedure is performed in edge regions, which are identified at each resolution scale during the wavelet reconstruction.

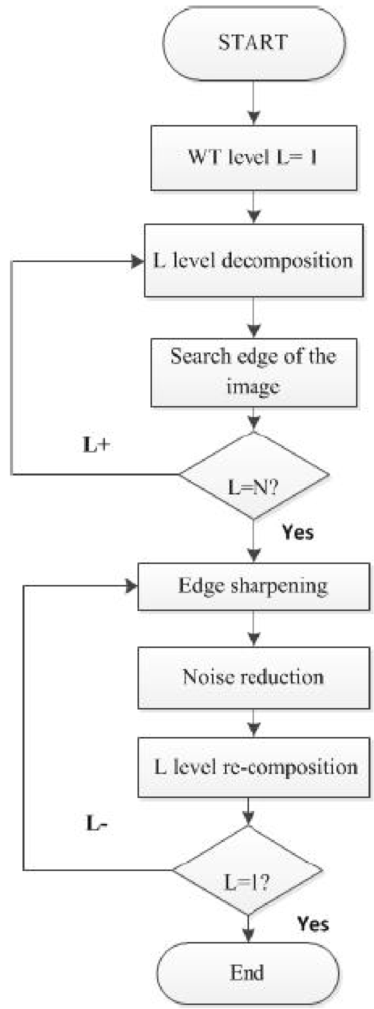
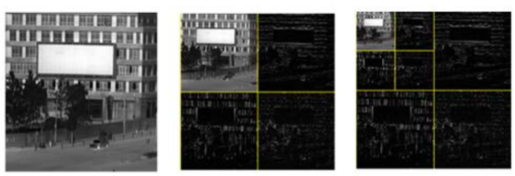


Figure 2*. The process of the proposed method to improve the quality of the infrared images*

When we filter in the frequency domain, spatial information is necessary to avoid edge blurring. In the spatial domain, we can hardly apply the edge selective filtering directly due to the various edges sizes. For filtering the infrared images containing various sized edges, a multi-scale approach based on the wavelet transform is proposed considering that it simultaneously provides both frequency and spatial information. Wavelet transform has the advantage that it decomposes an image into several frequency bands by using wavelet and scaling functions. Furthermore, the denoising algorithm can be easily implemented by low-pass filtering and high-pass filtering. Fig. 3 shows the examples of wavelet transform for an outdoor image. Fig. 3(a) is the original image, fig. 3(b) is the decomposition at level 1, where an original image is decomposed into 4 sub-band images. La1 is the low resolution image which is obtained by low pass filtering. Ld-h1, Ld-v1, and Ld-d1 represent the horizontal, vertical, and diagonal details, respectively. Fig.3(c) shows the decomposition at level 2. The 2-level transform is obtained by performing 1-level wavelet transform to the La1 image. Therefore, La1 is decomposed into La2, Ld-h2, Ld-v2, and Ld-d2. At the same time, the 1-level inverse wavelet transform reconstructs the original scaled image from the 4 sub-band images of level 1 by upsampling and filtering. Also the 2-level inverse wavelet transform can be performed by applying 1-level inverse wavelet transform to 4 sub-band images of level 2 and 1, sequentially. For edge selective filtering, we need to identify the edge location and orientation. To identify various sized edges, we perform the filtering in the wavelet domains. Considering that infrared images are characteristic of low SNR, the wavelet coefficients magnitudes of noise and detailed sub-band image signal are comparable, while the approximation band image is less affected by noise. Therefore, we don't expect to have ideal edge detection by simple thresholding of wavelet coefficients. Therefore, we proposed to perform structural information analysis on approximation band image at each wavelet decomposition level to identify edges.



(a) (b) (c)

Figure 3. The proposed method to enhance an outdoor infrared image by wavelet transform.(a) Original, (b) Decomposition at level 1, where an original image is decomposed into 4 sub-band. (c) The decomposition at level 2

Anisotropic diffusion model has been proved to be effective for detecting edges. Therefore, we have used the coherent nonlinear anisotropic diffusion model [17] based on the structure matrix. The matrix at each pixel takes the form:

$$J_\rho(\nabla I)=K_\rho *(\nabla I \otimes \nabla I)= K_\rho * (\nabla I \cdot \nabla I^T)\ (\rho \geq 0) \quad (2)$$

the symbol '$*$' stands for convolution and the convolution kernel is expressed as

$$K_\rho(x,y)=(2\pi\rho^2)^{-1}\exp\left(-\frac{x^2+y^2}{2\rho^2}\right) \quad (3)$$

where ρ is the integration scale over which the orientation information is averaged. The eigenvalue decomposition gives:

$$J_\rho(I)=(\omega_1\ \ \omega_2)\begin{pmatrix}\mu_1 & 0\\ 0 & \mu_2\end{pmatrix}\begin{pmatrix}\omega_1{}^T\\ \omega_2{}^T\end{pmatrix} \quad (4)$$

Where eigenvectors, ω_1 and ω_2, represent the directions with the maximum and minimum variations, respectively. Note that μ_1 and μ_2 are the eigenvalues characterizing the magnitudes of ω_1 and ω_2.

The image with anisotropic nature will tend to have considerable different eigenvalues. Usually these kind of pixels are located on the edges. Meanwhile, a pixel in homogeneous area tends to have an isotropic nature. Therefore, we can set an appropriate threshold, if the eigenvalue difference $||\mu_1| - |\mu_{12}||$ is large, we can identify the pixel as edge pixel, otherwise, it will be in flat areas.

In the filtering stage, noise reduction and edge enhancement are applied at each resolution level based on the edge information obtained in the analysis stage. We exclude the edge region when reducing the noise by low pass filtering procedure. We assume that the major part of noise is additive noise and low pass filtering is very effective in removing additive noise. For the edge-excluded filtering, we reduce wavelet coefficient in flat region without affecting those in edge regions.

For the edge region, we concentrate on improving the edge continuity and edge contrast through the directional filtering. It is performed by directional smoothing along the tangential direction and directional sharpening along the normal direction. To enhance the edges, we should make sure that noise is amplified in the procedure. Therefore, we perform the edge enhancement procedure in La bands which are less affected by noise.

EXPERIMENTAL RESULTS

The proposed algorithm is compared with the three regular filtering algorithms, named, median filtering, wiener filtering and bilateral filtering.

Figure 4 shows experimental results for an outdoor image captured in the daytime. In all the images after filtering, 4(b)-4(d), noise has been reduced more or less and therefore the image quality has been improved. However, details are not kept well or over-enhanced. 3(b) has similar details level as original image, only noise in flat area has been apparently reduced. 3(c) lost some details, especially for the borders between sky and buildings. 3(d) has been slightly over-enhanced with some artifacts. However, 5(e), the proposed method has given best result with relatively low noise and much better image details. It has excellent effect without looking artificial.

To give a quantitative measurement, we have performed the PSNR(Peak Signal to Noise Ratio) and MSE(Mean Square Error) calculation. Table 1 has showed the results. From the table, we can see that, among all these filtering methods, the proposed method has the lowest PSNR and MSE. It is consistent with the image qualities. For other methods, PSNR are not always consistent with MSE results, but very little difference.

In images above, we have discussed the effect of noise reduction. The other factor we are concerned is the details on the borders between different objects. To make this effect clear, we have made an edge detection operation with Canny operator. The results are shown in figure 5. In figure 5(b), much more edges can be viewed, so we can say that Median filtering has done good job in edge enhancement. For figure 5(c), we can also detect a lot of edges, but the images are relatively blurred and look artificial.

Figure 5(d) is not quite satisfying in this job, some edges are lost and artifact can be seen. The proposed method has given the best result in figure 5(e), with clear image and detailed edges. So we can say that our proposed also work pretty well in edge enhancement.

We make a measure by calculating the accumulative length of the edges. We assume the image size is by 1x1 as the base. It is a rough addition of the white lines in the images. The results have been listed in table 2. All the filtering methods have improved the edge details, however, median filtering, wiener filtering and the proposed method have given relatively good enhancement. In particular, the image given by proposed method has the finest edge identifications according to the calculations.

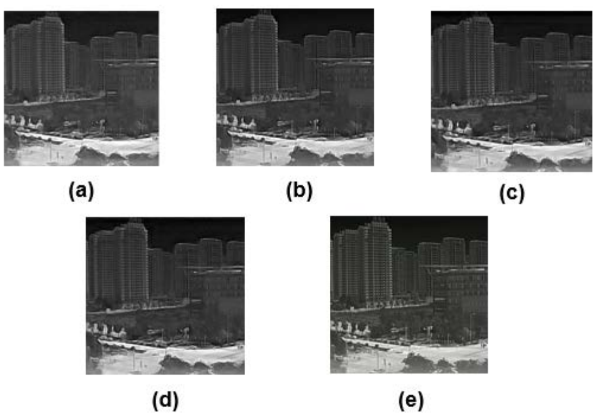


***Figure 4**. Experimental results for an outdoor image. (a) Original, (b)Median filtering, (c) Wiener filtering , (d)Bilateral filtering, (e) Proposed Method*

***Table 1**. Comparison of several filtering methods by PSNR and MSE result.*

Algorithm	Median	Wiener	Bilateral	Proposed
PSNR	42.135	41.085	38.512	42.521
MSE	0.0045	0.0043	0.0046	0.0043

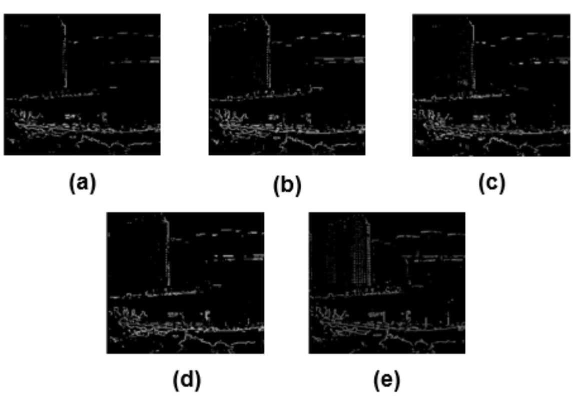


***Figure 5**. Edges with Canny operator for original image and images after filtering. (a) Original, (b)Median filtering, (c) Wiener filtering , (d)Bilateral filtering, (e) Proposed Method*

***Table 2**. Estimations of total edge lengths(image length scale: 1)*

Algorithm	Original	Median	Wiener	Bilateral	Proposed
Edge length	4	6.7	6	4.5	8.7

Conclusions

We have proposed an infrared image enhancement algorithm based on the wavelet transform. For infrared images, the signal noise ratio is relatively low in a wide range of frequency bands. So the regular algorithm based on magnitude statistics of wavelet coefficients in the decomposed image is not effective in separating the noise from the signals. In the proposed algorithm, to identify noise from the signal, we have performed the eigen-analysis at each resolution scale toward the decomposed image to acquire the structural information based on the coherent nonlinear anisotropic diffusion. Consequently, we adaptively apply the directional filtering and noise reduction procedures to the multi-resolution image. The experimental results show that the proposed algorithm considerably improves the infrared image quality without generating any noticeable artifact. The quantitative analysis also shows that the proposed method has better performance compared to the existing enhancement algorithms.

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