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Ridgelet Compression Method of Luggage X-ray Inspection Images

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Abstract

Inspecting luggage of passengers that get across the important passageway (such as airdrome, dock, depot etc.) has become broad safety precaution in the world. However, these inspected images have a large size of the datasets. In general, the useful and useless information in the luggage X-ray inspection image sequence don't be distinguished, so much computation resource and storage space are wasted. Considering the speciality of this sequence, we researched a compression method based on interesting region detection using ridgelet. The hybrid method was composed of ridgelet transform and background subtraction, which could detect the image with interesting region change efficiently. First, judge the present image whether with interesting luggage change or not. If having, compress the image with low loss or lossless. Else, compress the image with high compression ratio. The experiment showed the effectiveness of our compression method.

Keywords: X-ray inspection, compression, ridgelet, background subtraction

1. Introduction

X-ray devices have the ability to characterize a material at the molecular and atomic level. This ability is particularly important for detecting illicit materials. A number of X-ray devices are now commercially available. Those X-ray inspection images can be seen as video sequences, which have two notable characteristics, large data storage and line or super-plane singularities.

Ridgelet, a new analytic tool, proposed by Candès and Donoho in 1998[1], has the ability to describe linear or super-plane singularities. Simply speaking, the ridgelet transform can be described as the application of the wavelet transform to the coefficients of the Radon transform. In 2000 and 2002, M. N. Do and M. Vetterli proposed an orthonormal version of the ridgelet transform for discrete and finite size image, named finite ridgelet transform (FRIT)[5]. This paper indicated that ridgelet had compression potential in images with linear singularities. In 2006, Li ZENG, Zongjian LI et al proposed embedded image compression method using ridgelet for X-ray CT images[8], which had stong robustness.

In this paper, we research a compression method of luggage X-ray inspection images using

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ridgelet. Experimental results show that our method can detect the image with interesting region change efficiently, then compress the whole images more effectively. The organization of this paper is as follows. In Section 2, continuous ridgelet transform is introduced. In Section 3, finite ridgelet transform is introduced. In Section 4, we present our compression method. In Section 5, experimental results are conducted. Finally, we give the conclusion and future work to be done in Section 6.

2. Continuous Ridgelet Transform

Let us briefly review the continuous ridgelet transform defined by Candès and Donoho[1,2].

Given an integrable bivariate function $f(x)$, its continuous ridgelet transform (CRT) in R^2 is

$$CRT_f(a,b,\theta) = \int_{R^2} \psi_{a,b,\theta}(x) f(x) dx \quad (1)$$

Where the ridgelets $\psi_{a,b,\theta}(x)$ in 2-D are defined from a wavelet-type function in 1-D $\psi(x)$ as

$$\psi_{a,b,\theta}(x) = a^{-1/2}\psi\left((x_1 \cos\theta + x_2 \sin\theta - b)/a\right) \quad (2)$$

For each $a > 0$, each $b \in R$ and each $\theta \in [0,2\pi)$ .This function is constant along lines $x_1 \cos\theta + x_2 \sin\theta = const$. Transverse to these ridges, it is a wavelet.

For comparison, the (separable) continuous wavelet transform[3] (CWT) in R^2 of $f(x)$ can be written as

$$CWT_f(a_1,a_2,b_1,b_2) = \int_{R^2} \psi_{a_1,a_2,b_1,b_2}(x) f(x) dx \quad (3)$$

Where the wavelets in 2-D are tensor products

$$\psi_{a_1,a_2,b_1,b_2}(x) = \psi_{a_1,b_1}(x_1)\psi_{a_2,b_2}(x_2) \quad (4)$$

of 1-D wavelets, $\psi_{a,b}(t) = a^{-1/2}\psi((t-b)/a)$.

In 2-D, points and lines are related via the Radon transform, thus the wavelet and ridgelet transforms are linked via the Radon transform. More precisely, denote the Radon transform[4] as

$$R_f(\theta,t) = \int_{R^2} f(x)\delta(x_1 \cos\theta + x_2 \sin\theta - t) dx \quad (5)$$

Then the ridgelet transform is the application of a 1-D wavelet transform to the slices (also referred to as projections) of the Radon transform

$$CRT_f(a,b,\theta) = \int_R \psi_{a,b}(t) R_f(\theta,t) dt \quad (6)$$

3. Finite Ridgelet Transform

Finite ridgelet transform (FRIT) is a discrete orthonormal version of ridgelet transform proposed by Minh N. Do and Martin Vetterli[5], which is as numerically precision as the continuous ridgelet transform and has a low computational complexity. Finite ridgelet transform only suits for images of prime length, which is an important condition for its theory as well as a limitation of its application in image processing. Finite ridgelet transform can be obtained via a discrete finite radon transform and a 1-D discrete wavelet transform suitable for signals of prime length.

The finite Radon transform (FRAT) is defined as summations of image pixels over a certain set of "lines". Those lines are defined in a finite geometry in a similar way as the lines for the continuous Radon transform in the Euclidean geometry. Denote $Z_p = \{0, 1, \Lambda, p-1\}$ and $Z_p^* = \{0, 1, \Lambda, p\}$, where p is a prime number. The FRAT of a real function f on the grid Z_p^2 is defined as

$$r_k[l] = FRAT_f(k, l) = \frac{1}{\sqrt{p}} \sum_{(i,j) \in L_{k,l}} f[i, j] \quad (7)$$

Here, $L_{k,l}$ denotes the set of points that make up a line on the lattice Z_p^2, or, more precisely

$$\begin{aligned} L_{k,l} &= \{(i, j) : j = ki + l (\mathrm{mod}\ p), i \in Z_p\}, 0 \le k < p \\ L_{p,l} &= \{(l, j) : j \in Z_p\} \end{aligned} \quad (8)$$

The second step of finite ridgelet transform is to construct the new wavelet basis, which is suitable for 1-D signals of prime length and satisfies Condition Z[5]. The FRIT is orthogonal because such basis is applied on FRAT projection sequence to remove redundancy.

4. Our Method

4.1 Image Size

FRIT needs an input image of size $p \times p$, where p is a prime number, and this is an important limitation of this algorithm. Moreover, wavelets usually require a dyadic length signal and this is absolutely incompatible with the FRAT output (that is a matrix $p \times (p+1)$). In the text, we extended the length of the signal from p to n, where n is defined as:

$$n = \min\{x \in N : (x > p) and (x = 2^d), d \in N\} \quad (9)$$

4.2 Wavelet Transform

A fast wavelet transform is computed with a cascade of filtering with a low-pass filter $h(n)$ and a high-pass filter $g(n)$ followed by a factor 2 subsampling. In the text, we choose the Harr wavelet, which defined by[3]

$$h(n)=\begin{cases}\frac{1}{2} & n=0\\ \frac{1}{2} & n=1\\ 0 & otherwise\end{cases}\qquad g(n)=\begin{cases}-\frac{1}{2} & n=0\\ \frac{1}{2} & n=1\\ 0 & otherwise\end{cases}\tag{10}$$

4.3 Interesting Region Detection

In our application, the occurrence of a static background is very rare, hence, our algorithm should be flexible to the illumination changes that are gradual or sudden. The process of considering these changes is called background modeling. Once background modeling has been completed, the result is normally stored as an image called a background reference image. During luggage X-ray inspection images, where the current ridgelet transform image is subtracted from the background ridgelet transform image to detect interesting region change.

In the whole ridgelet coefficients, we only choose "two lines" as our resultant data, recorded $r_{l1}(t)$ and $r_{l2}(t)$. The "two lines" should be updated using information from different background. The "two lines" expected values and variances of frame at time t are defined as follows: (M is the total frames)

$$\mu_i=\frac{1}{M}\sum_{t=1}^{M}r_{li}(t),\ \ i=1,2\tag{11}$$

$$\delta_i^2=\frac{1}{M}\sum_{t=1}^{M}[r_{li}(t)-\mu_i]^2,\ \ i=1,2\tag{12}$$

When $r_{l1}(t)\notin[\mu_1-\delta_1,\mu_1+\delta_1]$ or $r_{l2}(t)\notin[\mu_2-\delta_2,\mu_2+\delta_2]$ is true, cursorily judge frame t having interesting region change, marking $t-1(\geq 1)$, t and $t+1(\leq M)$ at the same time. In light of the above discussion, all the marked frames are composed of a new image sequence $g_j(x,y)$. Considering the new image sequence should be binary, we define (μ_j,δ_j is the expected value and variance of each frame in the new image sequence)

$$\begin{cases}g_j(x,y)\in[\mu_j-\delta_j,\mu_j+\delta_j] & g_j(x,y)=1\\ g_j(x,y)\notin[\mu_j-\delta_j,\mu_j+\delta_j] & g_j(x,y)=0\end{cases}\tag{13}$$

4.4 Morphological Erosion

We use erosion for eliminating irrelevant details (such as illumination changes) from the binary images. For sets A and B in Z^2, the erosion of A by B, denoted $A\Theta B$, is defined as[6]

$$A\Theta B=\{z\,|\,(B)_z\subseteq A\}\tag{14}$$

In words, this equation indicates that the erosion of A by B is the set of all points z such that B translated by z, is contained in A.

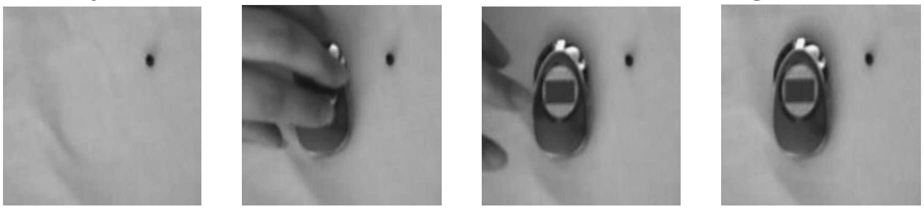
If $g_j(x, y)$ having been eroded, the size of region “1” is also larger than 7×7, we finally judge $g_j(x, y)$ having interesting region change.

4.5 Compression

We are more interested in those images which having interesting region change, but we face the same trade-off between quality and compression. For achieving different purposes, both lossless (such as Huffman code, block coding, arithmetic code etc.[9]) and lossy (such as wavelet code, cosine code etc.[7,9]) compression methods can be used. Those images which having interesting region change can be compressed with low loss or lossless, others compressed with high bit rate.

5 Experimental Results

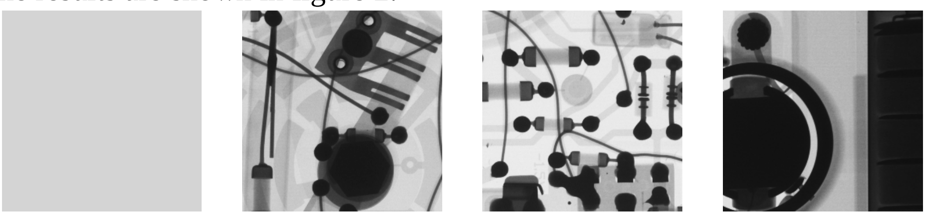
We tested our algorithm in two different ways. In the first experiment, we use a CCD camera connected to a PC to capture and process the incoming frames. The frame size is 256×256. There are 6 frames having interesting region change in the total 32 frames. Finally, besides these 6 frames, only 1 other frame is chosen. The results are shown in figure 1.



background frame some chosen frames

Figure 1. First experiment’s result

In the second experiment, we simulate some luggage X-ray inspection images. The image size is also 256×256. For each different luggage, the first image can be chosen correctly. But we do not get satisfactory results of choosing all interesting images, maybe lose 1 or 2 interesting image(s). The results are shown in figure 2.



background image some chosen images

Figure 2. Second experiment’s result

Table 1. Comparison between compression ratio

Lossless Compression	Method	Compression Ratio	
		experiment 1	experiment 2
	Huffman + arithmetic code	2.81	6.90

	our method	12.47	9.65

The results of compression ratio are shown in table 1. From it we know that the lossless compression ratios of our method are greater than the direct lossless compression of the whole images.

6 Conclusion

In many luggage X-ray inspection images, the useful and useless information don't be distinguished, so that much computation resource and storage space are wasted.

In image processing, especially in the compression of images, sparse representation received an increasing degree of attention because most information can be compacted into a small number of coefficients. Ridgelet, as a new analytic tool, can describe the signals which have linear or super-plane singularities. In our paper, we research a compression method of luggage X-ray inspection images using ridgelet. We first use ridgelet coefficients to detect the current image whether having interesting region change. If having, compress the image with low loss or lossless. Else, compress it with high compression ratio. Our method can detect the image with interesting region change efficiently. It also robust to the illumination changes gradual or sudden.

In different background, our method may detect a few images with uninteresting region change besides interesting region change or lose some interesting images. A future work is to update the "lines" of ridgelet coefficients to cater for different background model. Another possible future work is to update the detection process to cater for new information.

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