Research on Improved Fingerprint Image Compression and Texture Region Segmentation Algorithm

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Abstract: *Targeted at the image segmentation and compression problems commonly found in fingerprint image processing, this paper puts forward an improved image segmentation algorithm based on grayscale normalization and an improved image compression algorithm based on sparse matrix transform. The proposed algorithms are proved effective through checking computations. The research results show that: the normalization, open operation and smoothing of the original fingerprint image bring about significant improvement to image segmentation effect, effective elimination of the noise and non-texture interference information in the fingerprint image, and strong guarantee of the real-time effect of fingerprint image processing through the calculation of time periods; the redundancy of non-texture information in the image is effectively reduced by converting the fingerprint image into sparse domains, and the blocking effect is suppressed by calculating the mean grayscale and low frequency information in the image. According to the image compression experiment, the proposed algorithm demonstrates excellent rate distortion feature. The compression process preserves most of the key information features of the original image, and realizes high the imaging quality.*

Keywords: *Fingerprint image, Image compression, Image segmentation, Recognition rate.*

Introduction

Ranging from retina recognition, facial recognition to palmprint recognition, human body recognition technologies have infiltrated every corner of our society. Owing to the uniqueness, non-deformability and convenience, fingerprint recognition is the most commonly used identification method. The increasing popularity of fingerprint recognition calls for further improvement to fingerprint image quality and better recognition of blurry or severely deformed fingerprints. Much research has been done to facilitate the extraction of fingerprint information, and to establish a sound fingerprint information database [1, 3, 4, 10, 11, 13, 14, 16, 18].

At present, the fingerprint information processing technologies mainly include fingerprint image enhancement [5, 7, 8, 12], fingerprint image compression [6, 9], fingerprint image segmentation [2, 15, 17] and so on. Specifically, fingerprint image segmentation refers to the fingerprint image preprocessing technology that distinguishes the interference sources (e.g. non-fingerprint information, noise, etc.) in the image from fingerprint feature points; fingerprint image compression is a technology to save a large number of fingerprint images. Both of them are of great importance to fingerprint recognition.

Targeted at the image segmentation and compression problems commonly found in fingerprint image processing, this paper puts forward an improved image segmentation algorithm based on grayscale normalization and an improved image compression algorithm based on sparse matrix transform. The proposed algorithms are proved effective through checking computations. The research findings provide a theoretical guidance to fingerprint processing.

Fingerprint texture area segmentation algorithm

Calculation method

In fingerprint image segmentation, the texture area in the fingerprint image is segmented based on variation in grayscale and direction information. The mean grayscale of the original image can be expressed as:

$$M = \frac{1}{W \times H} \sum_{i=1}^{W} \sum_{j=1}^{H} I(i, j). \tag{1}$$

Image variance:

$$VAR = \frac{1}{W \times H} \sum_{i=1}^{W} \sum_{j=1}^{H} \left[I(i, j) - M \right]^2. \tag{2}$$

Normalization of fingerprint image pixels:

$$\tilde{I}(i, j) = \begin{cases} M_0 + \sqrt{\dfrac{VAR_0 \left[I(i, j) - M \right]^2}{VAR}} & I(i, j) \geq M \\ M_0 - \sqrt{\dfrac{VAR_0 \left[I(i, j) - M \right]^2}{VAR}} & I(i, j) < M, \end{cases} \tag{3}$$

where M is the mean grayscale of the image; W and H are the width and height of the fingerprint image, respectively; VAR and VAR_0 are the variance of the original image and the desired variance, respectively; M_0 is the desired mean grayscale.

The image normalized and divided into 9 sections (3×3). The difference between mean grayscales in the horizontal and vertical directions $G_{di}(1, 3)$ is calculated by Eq. (4), and the difference between the grayscales in the +45° and −45° $G_{di}(2, 4)$ is calculated by Eq. (5):

$$D_{di}(1,3) = \left| G_m(1) - G_m(3) \right|, \tag{4}$$

$$D_{di}(2,4) = \left| G_m(2) - G_m(4) \right|, \tag{5}$$

where G_m is the mean grayscale. The possible direction R_l of fingerprint ridge is calculated based on G_m:

$$R_l = \begin{cases} 1 & D_{di}(1,3) > D_{di}(2,4) \\ 2 & D_{di}(1,3) \leq D_{di}(2,4) \end{cases}. \tag{6}$$

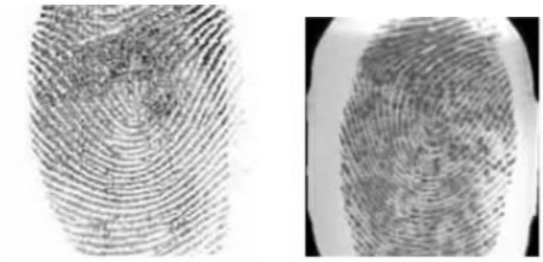
If and only if under the determination condition of Eq. (7), the determined value of the ridge of (*i*, *j*)-th element in the normalized fingerprint image $Dir(i, j) = R_l$; otherwise, $Dir(i, j) = R_l + 2$.

$$\left|\tilde{I}(i,j) - G_m(R_l)\right| < \left|\tilde{I}(i,j) - G_m(R_l + 2)\right| . \tag{7}$$

The texture area extraction is preceded by determining the segmentation template based on *Dir*, counting the number of points in the template with the pixel value of 0, and carrying out smoothing of the image.

Analysis of fingerprint image test results

The above procedures are adopted for fingerprint image processing in this research. Fig. 1 shows a fingerprint left on a piece of paper (the paper image) and the same fingerprint collected by a collector (the collector image).



(a) Paper image (b) Collector image

Fig. 1 Fingerprint images used in the test

The two fingerprint images are processed by the grayscale variance method, the gradient method and the proposed algorithm, respectively, and the results are shown in Fig. 2. Fig. 2(a) displays the results of the paper image, and Fig. 2(b) presents the results of the collector image.

(1) (2) (3)

(a) Segmentation results of the paper image

(1) (2) (3)

(b) Segmentation results of the collector image

Fig. 2 Fingerprint mage segmentation results of the three methods

The segmentation results of the paper image demonstrate that: despite the ideal elimination of the interference background in the fingerprint texture area, the grayscale variance method does poorly in noise segmentation, and leaves some irregular ridges in the image, as shown in SubFig. (1) of Fig. 2(a); compared with the grayscale variance method, the gradient method does better in removing the noise and background areas from the image, featuring better segmentation effect; the proposed algorithm also achieves good segmentation effect. The segmentation results of the collector image indicate that: the grayscale variance method fails to remove the influence of the border region, and wastes more time in the secondary processing of the image; with heavy losses of finger ridges, the gradient method results in heavy interference to the image and seriously affects the accuracy of fingerprint matching; the proposed algorithm, however, greatly improves the reliability of image feature extraction as they overcome the defects of conventional image segmentation algorithms, such as the loss of feature points and over-segmentation.

The images are then processed jointly by the grayscale variance method and the gradient method (the joint method). The results of the joint method, variance method, gradient method and the proposed algorithm are used for an image matching test. 500 fingerprints are selected. The hit rate and miss rate are listed in Table 1.

As shown in the table, among the four methods, the variance method and the gradient method have low hit rates, 84% and 88% respectively, and share the same miss rate of 4%; the joint method improves the hit rate to 92% and lower the miss rate to 2%; the proposed algorithm boasts a hit rate of 95% and a miss rate of 0%. The results reveal that the proposed segmentation method effectively improves the matching rate and achieves accurate segmentation of fingerprint images.

Table. 1 Matching results of different segmentation algorithms

Algorithm	**Variance method**	**Gradient method**	**Joint algorithm**	**Proposed method**
Miss rate (%)	4	4	2	0
Hit rate (%)	84	88	92	95

Fig. 3 shows the time consumption of the joint image processing algorithm and the proposed algorithm.

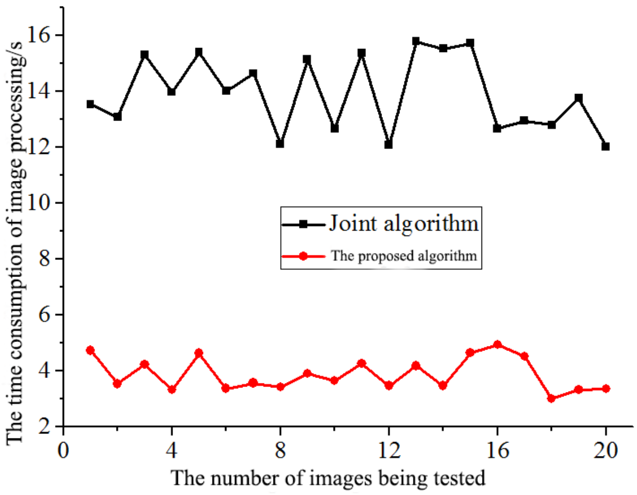


Fig. 3 Comparison of images decomposed by different methods

It is clear that the joint algorithm costs much more time than the proposed algorithm. This is because the joint algorithm processes the images twice, respectively by the variance method and the gradient method. The heavy time consumption undermines the timeliness of image processing.

Research on fingerprint image compression technology

Fingerprint images are widely used in identification. Every day, countless fingerprint data are uploaded to the central storage space, making it necessary to compress and save the data by image compression technology. However, the conventional image compression methods are accompanied by heavy loss of feature points and information. Therefore, fingerprint images should be compressed by special methods. This paper suggests compressing fingerprint images by an improved image compression algorithm based on sparse matrix transform.

Image fusion test results

Fig. 4 shows the procedure of the fingerprint image compressed based on improved sparse matrix transform. The algorithm is mainly divided into learning training phase, fingerprint image coding phase and image decoding phase.

The learning and training phase mainly refers to the learning of the fingerprint feature in the central fingerprint database, and the matching training according to the corresponding features. The training process can be expressed by the Eq. (8):

$$\min\{\|Y - AX\|_F^2\} \quad \forall i \quad \|X_i\|_0 < T\ , \tag{8}$$

where X is the sparse matrix; X_i is the sparse vector of the i-th sample; T is the maximum number of nonzero vectors in the matrix.

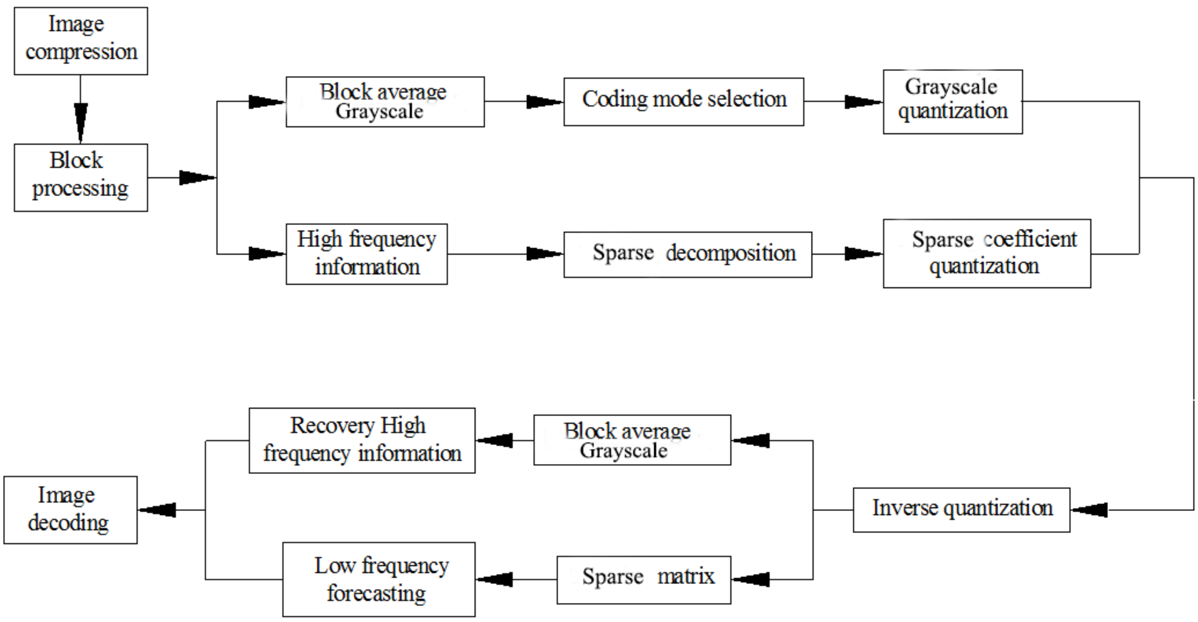


Fig. 4 Flow chart of fingerprint image compression
based on improved sparse matrix transform algorithm

In the fingerprint image coding phase, the image segmentation method proposed in the previous section is used to divide the image into several units and to obtain the sparse coefficient of the response. The image decoding phase uses the inverse quantization model to obtain the average grayscale and sparse matrix of the block, deduce the high frequency response information and low frequency prediction information, and finally get the decoded image of the fingerprint.

Eq. (8) is a typical mathematical model of sparse matrix decomposition. In the field of image processing, Y is the image signal to be processed, and X is the direction vector of signal Y. The specific steps of sparse matrix decomposition are as follows: input the image signal Y, the optimal sparse coefficient L and the residual signal; use the quantization parameter Q to quantize and dequantize the direction vector to obtain the sparse vector set $\{X_{thin}\}$; extract the maximum vector in $\{X_{thin}\}$, set the residual vectors to zero, and iterate X, i.e. $X = X + X_{thin}$; output X when the iteration termination conditions are satisfied.

After the fingerprint image is transformed into the sparse domain, subsequent calculation is needed to obtain the quantization mapping function. The conventional quantization mapping function is improved as follows:

$$Q_{gray} = \lambda \times Q_{space} \;, \tag{9}$$

where Q_{gray} and Q_{space} are the quantization parameters of grayscale and sparse coefficient, respectively; λ is the mapping coefficient, which is set as 12.5 in this paper.

Analysis of image compression test results

The test data are extracted from the central fingerprint database. In total, 500 fingerprint images are selected, in which 150 images are used for learning and training and the other 350 images are used to verify the accuracy and effectiveness of the proposed algorithm.

The image compression performance is evaluated by the use rate distortion function. The larger the value of rate distortion, the smaller the loss of feature points in image compression. The x-axis of the rate distortion curve represents the bit rate of the compressed image; the y-axis represents the signal-to-noise ratio R_{PSN} after image decoding. The R_{PSN} is calculated by Eq. (10):

$$R_{PSN} = 10\lg\left[\frac{\left(2^n - 1\right)^2}{E_{mse}}\right], \tag{10}$$

where E_{mse} is the mean square error of the original image and the processed image. The JPEG 2000 algorithm, K-svd-sr algorithm and the proposed algorithm are used to compress the fingerprint images, and the rate distortion curves of the three algorithms are shown in Fig. 5.

It is seen that when the bit rate is less than 0.85, the rate distortion of the proposed algorithm is obviously higher than that of JPEG 2000 and K-svd-sr; when the bit rate is the same, the signal-to-noise ratio of the proposed algorithm is 0.5 dB higher than that of the other two algorithms. The results indicate that the proposed algorithm boasts better image decoding quality.

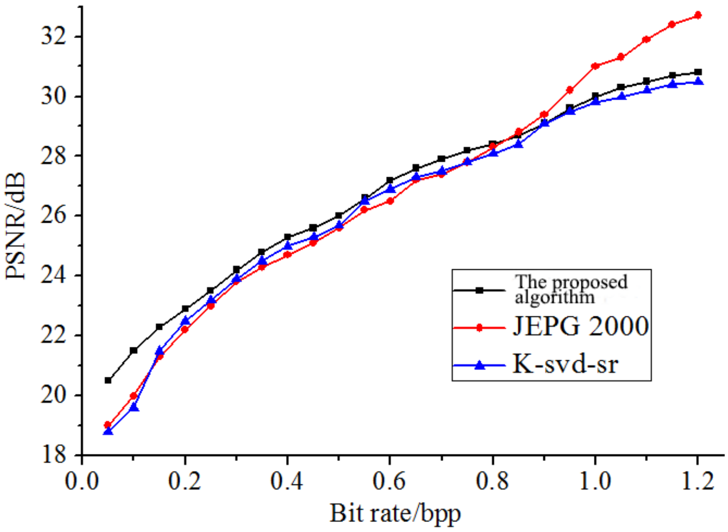


Fig. 5 Rate-distortion curve of 3 kinds of algorithms

Fig. 6 compares the quantification effect of the proposed algorithm and the K-svd-sr algorithm. With better quantification effect, the proposed algorithm can effectively improve the rate distortion performance of the overall image compression framework.

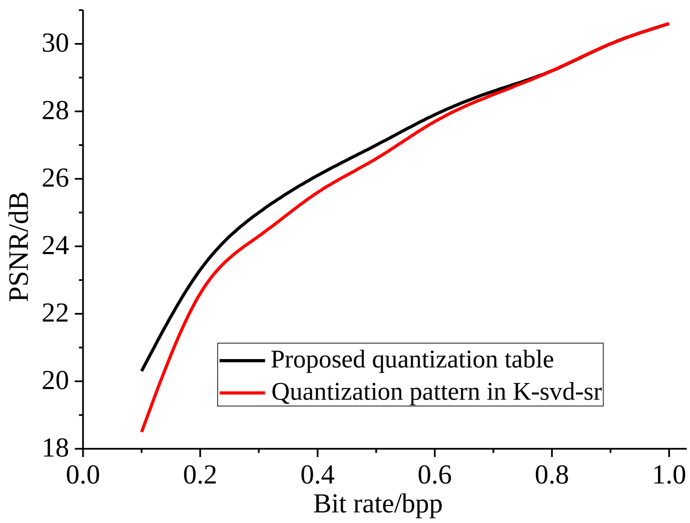


Fig. 6 Comparison of image compression between two quantization modes

Fig. 7 shows the selected original fingerprint image and the decoded image obtained by the three image compression processing methods. It can be seen that the proposed algorithm preserves most of the key information features of the original image, and realizes high the imaging quality. In contrast, the JPEG9 algorithm and the K-svd-sr algorithm suffer from obvious block effect, lose many details, and lead to serious image distortion. The results further verify the effectiveness of the proposed method.

Fig. 8 presents the matching rate of the three image compression algorithms. The matching rate of the proposed algorithm is obviously higher than that of JPEG 2000 and K-svd-sr. At the code rate of 1.0, the matching rate of the proposed algorithm reaches 94.7%. This means the proposed algorithm achieves better compression rate and allows the fingerprint database to store more fingerprint images.

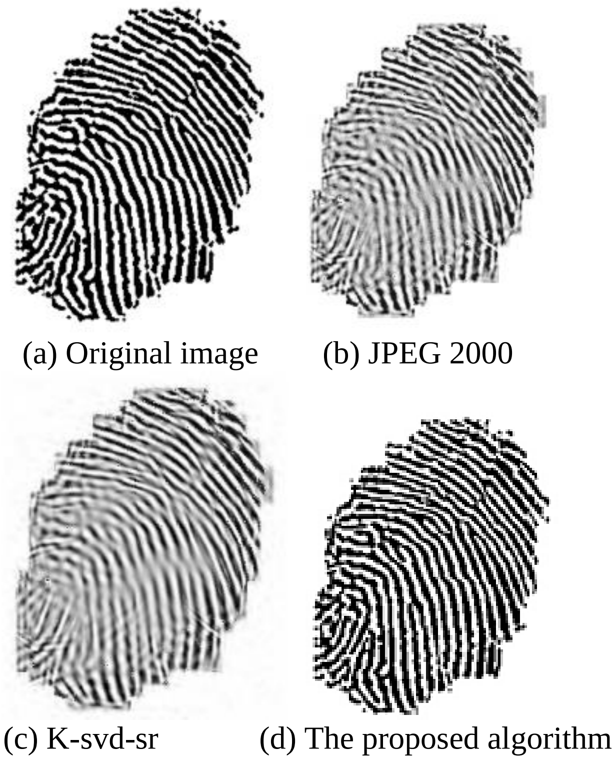


Fig. 7 Image decoding results of 3 algorithms

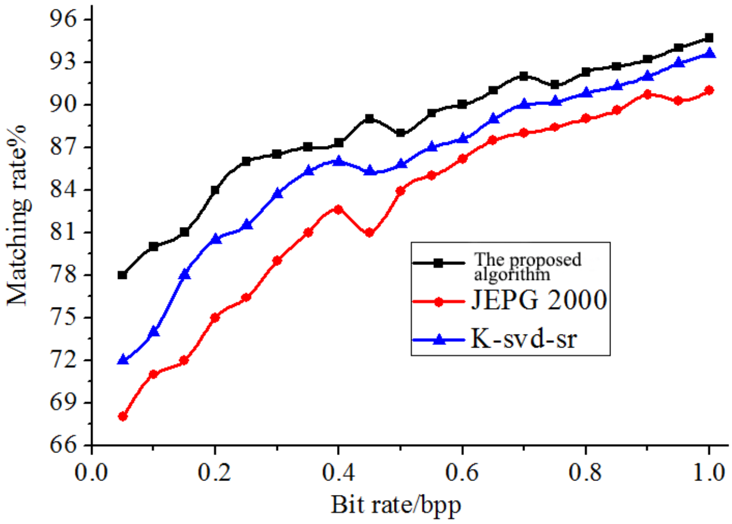


Fig. 8 Image compression matching rate of the 3 algorithms

Table 2 shows the calculation time of the three algorithms.

Table 2. Calculation time of different algorithms

Bit rate	0.1	0.3	0.5	0.6	0.7	0.8	1.0
JPEG 2000	0.32	0.35	0.34	0.36	0.33	0.34	0.35
K-svd-sr	1.33	1.39	1.95	2.38	3.59	4.06	4.36
The proposed algorithms	1.78	1.89	2.49	2.95	4.21	4.88	5.56

The JPEG 2000 algorithm shows an average computing time of merely 0.35 s, shorter than that of the other two algorithms. The proposed method, however, consumes the longest time. The reasons are as follows: JPEG 2000 algorithm, as a mature and simple method, pursues faster computing speed at the expense of image quality; the proposed algorithm is more time-consuming due to the existence of iterative calculation. However, the maximum computation time (5.56 s) of the proposed algorithm still falls within the acceptable range.

Conclusion

Targeted at the image segmentation and compression problems commonly found in fingerprint image processing, this paper puts forward an improved image segmentation algorithm based on grayscale normalization and an improved image compression algorithm based on sparse matrix transform. The proposed algorithms are proved effective through checking computations. The conclusions are listed below:

1) The normalization, open operation and smoothing of the original fingerprint image bring about significant improvement to image segmentation effect, effective elimination of the noise and non-texture interference information in the fingerprint image, and strong guarantee of the real-time effect of fingerprint image processing through the calculation of time periods;
2) The redundancy of non-texture information in the image is effectively reduced by converting the fingerprint image into sparse domains, and the blocking effect is suppressed by calculating the mean grayscale and low frequency information in the image. According to the image compression experiment, the proposed algorithm demonstrates excellent rate distortion feature. The compression process preserves most of the key information features of the original image, and realizes high the imaging quality.

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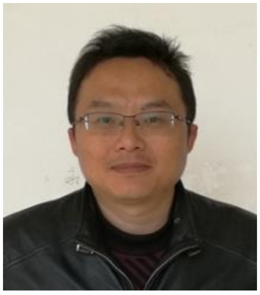

Kun Liu is coming from Qujing, Yunnan, China, Han ethnicity. He obtained his M.Sc. degree and currently is a lecturer of Computer Education, Artificial Intelligence, etc. Start working in 2002, Kun Liu is mostly engaged in educating undergraduates in the field of computer science, teaching the courses of Computer Organization, The C Programming Language, Object-oriented Programming, Fundamentals of Computer Science and Technology, Computer Fundamentals, etc. Over the years, Kun Liu has presided over 1 university-level project, participated in 3 provincial projects, published 20 papers and co-edited a textbook.