Compression of Chinese Character Patterns in Document Images Based on Rectangular Region Partitioning Using Contour Information and Huffman Coding*

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Abstract

Document image compression is important in modern communication systems, and many lossless/lossy compression algorithms have been proposed for a variety of documents. In documents with Chinese characters, there are 5401 commonly used Chinese character patterns. It requires a large amount of space to store all Chinese character the patterns of different fonts in computer systems. However, the compression of Chinese character patterns has not been extensively studied. In this paper, a new document image compression method is proposed. The purpose is to provide an effective encoding algorithm for Chinese character patterns and in the mean time obtain good compression results for general documents. The proposed method includes rectangular region partitioning, encoding of rectangular regions, and encoding of contour information. An input image is first partitioned into nonoverlapping blocks, and each block that contains black pixels is partitioned into nonoverlapping rectangles. The rectangles are then encoded in an effective fashion. For the purpose of lossless compression, contour information is exploited to encode the contour blocks with static Huffman coding. Experimental results showed that the proposed method is not only suitable for Chinese documents but also has good performance for general documents.

Key words: Document image compression, Chinese character pattern, Rectangular region partitioning, Contour information encoding, Huffman coding.

1. Introduction

With advances in communication technologies, lots of documents in traditional office environments are scanned into computers as images for fast archiving and transmission. Document images with printed and handwritten information in black and white pixels constitute a subclass of digital images. The sizes of scanned documents are usually large and so require large storage space and time to store and transmit. Document image compression (DIC) is the key technique to solve these problems.

Many lossless/lossy DIC algorithms have been proposed for a variety of documents [1, 8, 9]. Run-length coding and CCITT Group 3 and 4 compression algorithm are conventional methods for lossless compression of document images [2]. The JBIG standard combining a local context model with arithmetic coding has the best performance in lossless compression [2, 3]. However, the JBIG algorithm is slow in arithmetic coding, compared to conventional CCITT Group 3 and 4 compression algorithms. A template matching method for DIC was proposed by Witten et al. [4], in which connected groups of pixels, corresponding approximately to individual characters, are first extracted from the image. These connected components are then matched against an adaptively constructed library of patterns seen so far, and the resulting sequence of symbol identification numbers is coded. When the document image contains mostly alphanumeric symbols, the compression result is much better than those methods mentioned previously. However, for those images that contain complex strokes such as Chinese characters, it is hard to apply simply the template matching method to achieve effective compression. Mohamed and Fahmy [5] proposed a method that partitions the input image into a near minimum number of nonoverlapping rectangles and encodes the coordinates of the opposite vertices of each rectangle. Although this method is fast and the compression result is better than most conventional methods, the partitioning algorithm produces a lot of small rectangles around skewed strokes of characters or skewed line drawings. In this situation, encoding of the opposite coordinates of each rectangle will be less efficient. In the above studies, it is clear that the compression of Chinese characters is difficult and demands further research.

Targetting the difficulty of compressing Chinese character patterns, Tsay et al. [6] proposed a redundancy-gathering algorithm based on arithmetic coding. Though the result of simulation in this study is good, the computational complexity is high since a huge tree of nodes are used. Lai and Liaw [7] presented a lossless compression method by 2-D run-lengths with line-segment prediction. Though the method is fast and has good compression results, there is still much to improve.

In this study, we propose a novel lossless DIC method, especially suitable for Chinese character patterns. Since each Chinese character pattern is composed of many straight strokes, it is efficient to partition the strokes of each character into nonoverlapping rectangular regions as Mohamed and Fahmy [5] proposed. Furthermore, it is obvious that there exists a high correlation between the boundaries of strokes. A local context model based on pixels is commonly established to take advantage of the correlation [9]. The proposed method also establishes a local context model, but based on blocks instead. The simulation results show that the proposed method is not only efficient for compressing specific

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document images containing lots of Chinese character patterns but also suitable for general document images.

The remainder of this paper is organized as follows. In Section 2 we describe the principle of the proposed DIC method. In Section 3 we describe the proposed rectangular region partitioning technique. Algorithms for encoding of the rectangular regions and encoding of contour information are proposed in Sections 4 and 5, respectively. We will also examine the effectiveness of each proposed algorithm right after the algorithm is described in each section. The paper concludes with Section 6.

2. Principle of Proposed Method

As shown in Fig. 2, the proposed method includes block map generation, rectangular region partitioning, encoding of rectangular regions, and encoding of contour blocks.

The proposed method is based on processing blocks, so an input image S is first decomposed into nonoverlapping 2×2 blocks. In each block, there are 16 different combinations of black and white pixels, as shown in Fig. 1. A block map B is also generated when the image S is decomposed. The map B is a ternary matrix with the size of a quarter of that of the input image S, i.e., if the size of S is $2^n\times2^n$, then that of B is $2^{n-1}\times2^{n-1}$. The elements b_{ij} of B are defined as

$$b_{ij}=\begin{cases}0, & \text{if all the pixels in the correspond ing block are white,}\\ 1, & \text{if all the pixels in the correspond ing block are black,}\\ 2, & \text{otherwise,}\end{cases} \quad (1)$$

where $i, j = 1,2,\ldots,2^{n-1}$. In Equation (1), b_{ij}=0 represents a *white block*, b_{ij}=1 represents a *black block*, and b_{ij}=2 represents a *mixed block* including black and white pixels. Based on the information of the block map B, an approximate image of the original image can be obtained. The difference between the original input image and the approximate image mostly comes from the contours of uniform regions in the original image. If the block map is compressed and transmitted, then the receiver can decompress the block map and reconstruct a lossy version of the original image by the block map. If the contour information is also compressed and transmitted, then the receiver can restore the original image by the use of the combined data of the contour information as well as the block map. Hence, the subsequent stages of the proposed method aim at good compression of the block map and the contour information.

As mentioned earlier, Chinese character patterns contain a lot of straight strokes. To exploit the general features of Chinese character patterns for compression, new rectangular region partitioning and encoding method, are proposed to partition the block map into nonoverlapping rectangles and then encode them. It is worthy to notice that the use of the block map makes the characteristic of straightness of strokes more apparent than that in the original image; and so fewer rectangles will be produced from the block map than from the original image. And this makes the encoding of the block map more efficient.

Finally, to encode the contour information, a local context model is established to model the relation between each contour block and its 8 neighbor blocks. The context model is developed according to our observation that the probability of the appearance of a specific block in the center of a 3×3 block group varies with different combinations of the neighboring blocks. As a result, the efficiency of the proposed contour block coding can be improved further by the use of static Huffman coding.

The details of the proposed processes of rectangular region partitioning, encoding of rectangular regions, and encoding of contour information are described in the following sections.

3. Block Map Partitioning

The block map of an input image makes the straightness of strokes more apparent, so it is advantageous to partition the regions of strokes into a number of rectangles. Several techniques have been proposed to partition a region into rectangles [10, 11]. Though Mohamed and Fahmy's method [5] is greedy and not optimal, it is fast and near optimal. In addition, the block map in our technique is a ternary matrix; only the binary matrix, however, is considered in Mohamed and Fahmy's method [5]. Therefore, a new partitioning algorithm, called block map rectangular partitioning (abbreviated as BMRP), is proposed in this study to take advantage of using the block map.

As an example, see Fig. 4(a) which is the block map of a Chinese character image. By applying the proposed BMRP algorithm to the block map in Fig. 4(a), the shadowed region (stroke region) in the block map can be partitioned into nonoverlapping rectangles as shown in Fig. 4(b). For the compression purpose, an encoding matrix E is generated in the BMRP process, as shown in Fig. 4(c). The size of the matrix E is the same as that of the matrix B, and the element e_{ij} of E is defined as

$$e_{ij}=\begin{cases}1, & \text{if } (i,j) \text{ is the top left vertex of a rectangle;}\\ 2, & \text{if } (i,j) \text{ is the bottom right vertex of a rectangle;}\\ 3, & \text{if } (i,j) \text{ is an isolated block or a mixed-inner block;}\\ 0, & \text{otherwise.}\end{cases} \quad (2)$$

Note that e_{ij}=3 means that the block b_{ij} is isolated, or is a block with mixed color (i.e., b_{ij}=2) and the 8 neighboring blocks of b_{ij} are of mixed color or black. Isolated blocks exist in contours that contain isolated pixels in the input image. On the other hand, by using the block map, the proposed method partitions the input image in a low resolution. When a small hole exists in the center of a bold stroke of a character, it will result in a mixed block having eight black or mixed neighboring blocks. This situation happens in small characters or small defects in strokes, as shown in Fig. 3. For the purpose of lossless compression, such mixed-inner blocks also have to be tracked and coded. By encoding the matrix E, the block map can be compressed in an efficient way.

The BMRP algorithm proceeds in a raster scan fashion. When a new rectangle is found, the corresponding locations of the two opposite vertices in matrix E are assigned nonzero values. The original rectangle can be reproduced from the two nonzero elements of the be reproduced from the two nonzero elements of the matrix E. As a result, all rectangles found in the block map can be reproduced by the information provided in matrix E. The detail of the BMRP algorithm is described as follows.

***Algorithm 1 Block Map Rectangular Partitioning* (BMRP)**

Step 1: Scan the blocks in the input $m \times n$ block map matrix B one by one and encode the result with a matrix E.

Step 2: If an unprocessed black or mixed element b_{ij} in B is found (b_{ij} = 1 or 2), then a new rectangle is encountered. Set e_{ij} = 1 as the top left vertex of the new rectangle and set $k = j$. Perform the following steps.

(1) If $b_{i(k+1)}$ is not white ($b_{i(k+1)}$ = 0) or is processed, then set $k = k + 1$ and repeat Step 2(1).

(2) Regard e_{ik} as the top right vertex of the new rectangle and set l = i.

(3) In a row-by-row manner, scan downward the matrix B in the column range between the column location, j, of the top left vertex and the column location, k, of the top right vertex. Check if the segment in the next row bounded by locations (l+1, j) and (l+1, k) meets either of the following two conditions.

(Condition 1) More than one white block exists in this row.

(Condition 2) Blocks, $b_{(l-1)(j-1)}$ and $b_{(l+1)(k+1)}$, are both unprocessed black or unprocessed mixed blocks ($b_{(l+1)(j-1)}$, $b_{(l+1)(k+1)}$=1 or 2).

If neither of the condition is met, then set $l = l + 1$ (i.e., to scan the next row) and repeat Step 2(3);

(4) If coodinates (l, k)=(i, j), then set e_{lk} = 3 (isolated block); else, set e_{lk} = 2 as the bottom right vertex of the rectangle.

(5) For each block, b_{pq}, in the new rectangle, set each block in the new rectangle as being processed, and if b_{pq}=2 (mixed block) and all of its eight neighbor blocks are not white, then set e_{pq}=3 (inner mixed block).

Step 3: Output the matrix E.

We shall first examine the performance of the BMRP algorithm. Two categories of images are used as inputs. For Chinese characters, there are at least 5401 commonly used characters. The sung-style, formal-style, and running-style fonts are commonly used in printing. 200 characters of each font are randomly chosen in our experiment. Each character is with a resolution of 64×64. Fig. 5 shows an example of the experimental images of Chinese character patterns. To test the effectiveness of the BMRP for general document images, six document images of different types and sizes are used. Each general document image is scanned in 300dpi. These images are shown in Fig. 6.

Table 1 summarizes the experimental result of using the BMRP algorithm. The average numbers of produced rectangles per character pattern of each font were 43.8, 48.5, and 36.8, respectively. The running-style fonts resulted in more rectangles than the other two fonts. A possible reason is that the running-style fonts contain more skewed strokes than the other two fonts and skewed strokes are partitioned into more rectangles than vertical or horizontal strokes. Furthermore, comparing with Mohamed and Fahmy's method [5], we found that the number of rectangles generated by the BMRP algorithm was about half of that generated by Mohamed and Fahmy's method [5]. The reduction in the number of rectangles will yield better results in rectangle and contour information encoding, proposed in the following sections.

4. Encoding of Rectangular Regions

After the block map is partitioned into rectangles and the matrix E is produced, the next stage is to encode the coordinate information. The encoding algorithm should be efficient to maintain the advantage of the BMRP algorithm. The proposed algorithm for this purpose processes input matrices from left to right and from top to bottom as the BMRP algorithm. There are three possible nonzero values in the matrix E, and each nonzero value is assigned a different codeword. These codewords are not equal in length, because the probability of the appearance of each nonzero value is not the same. Basically, the occurrence probability of the matrix element '1' (top right block) and '2' (bottom block vertex) are much higher than '3' (isolated or inner mixed block), so it is efficient to use the static Huffman code to encode these symbols. Table 2 gives the code table used in the experiment.

In another aspect, skewed strokes result in small rectangles and the opposite vertices of these rectangles are usually connected. That is, if two rectangles are connected, the bottom right vertex of the upper rectangle may be a neighbor of the top left vertex of the lower rectangle. This shows that if a chain code type method is employed, the codes for compressing these vertices can be more compact. In the proposed algorithm, if e_{ij} is a nonzero element in matrix E, a tree T_{ij} whose root is e_{ij} is constructed. Each node, p, of the tree has the following properties.

Property 1: p is a nonzero and unprocessed element in the matrix E.

Property 2: If q is a nonzero element in the matrix E and is a southwestern (*sw*), southern (*s*), southeastern (*se*), or eastern (*e*) neighbor of p, then q is also a node of the tree T_{ij}. We said that p is the parent node of q, and q is the child node of p.

Property 1 says that each node of the tree T_{ij} must be a nonzero element in the matrix E. And Property 2 says that the tree T_{ij} is expanded from e_{ij} in four directions (*sw*, *s*, *se*, and *e*) by including each nonzero neighboring element into the tree. The expansion of the tree T_{ij} stops when no nonzero neighbor is found. A depth first search (dfs) algorithm is used to expand the tree. If a nonzero child e_{pq} is encountered during the dfs, codewords used to encode the nonzero element's direction and value are assigned. Table 3 shows the codewords used to encode the directions in our experiment and Table 2, as mentioned previously, shows the codewords used to encode the nonzero value. Then, the tree is expanded by including nonzero children whose parent is e_{pq} and the dfs algorithm recursively traverses the children expanded using dfs. At last, the dfs algorithm stops when all the children in the tree are visited and no more nonzero child is found.

We illustrate the basic concepts of the proposed algorithm by Fig. 7, which shows the tree structure of the relationship defined in the proposed algorithm. Fig. 7(a) shows all possible branchings from a nonzero element during executing the proposed algorithm. Fig. 7(b) shows the final tree structure. The black boxes represent nonzero elements and the white boxes represent zero elements in the matrix E. In Fig. 7(a), e_{ij} is the nonzero root of the tree. The tree is expanded in four directions by including the root's nonzero neighbors. For example, nodes, A, B, C, and D are the southwestern (*sw*), southern (*s*), southeastern (*se*), and eastern (*e*) neighbors of the element e_{ij}, respectively. And only A is a nonzero element (black box). As a result, a solid line between e_{ij} and A is used to represent a *real* branch in the tree, and the other three dashed lines between the pairs of e_{ij} and B, e_{ij} and C, and e_{ij} and D are used to represent *fake* branches in the tree. The proposed algorithm first encodes node A and then search A's child nodes to see if any nonzero child exists. If there exists a nonzero child node of A, the nonzero child node is expanded in the tree. Otherwise, the proposed algorithm traces upward to A's father node and searches if any nonzero child exists. At last, the algorithm stops when no nonzero child exists. In this example, after node A is visited and encoded, node F and node K are visited and encoded, respectively. In this process, it is found that there is no nonzero child of node K, so the trace goes upward to node F and then node G is processed and encoded. At last, no nonzero child of node G was found and the algorithm stops. The final tree structure is generated to be Fig. 7(b). Note that there is a dashed line between node G and node K because node K is already visited and encoded in the tree as a child node of F.

An algorithm is presented below to summarize the proposed rectangular region encoding process as described above.

Algorithm 2 Rectangular Region Encoding

Step 1:Read in the matrix E with size $m \times n$ which is to be encoded. Use 32 bits to encode m first. For each row i in E, perform the following steps.

Step 2:If all the elements e_{ij} in row i are zero (where j=1,2,...,n), then represent the row by a binary value "0"; else, go to step 3.

Step 3:(Encode nonzero elements) If a nonzero element is encountered in row i, then add a prefix "1" to the code, indicating the existence of a nonzero element, and then attach the codeword that identifies the nonzero element, 1, 2, or 3 to the prefix. The column location of e_{ij} is specified by b bits which are defined by the following Equation (3):

$$b = \begin{cases} \lceil \log_2 n \rceil, & \text{if } e_{ij} \text{ is the first nonzero element:} \\ \lceil \log_2 (n-k) \rceil, & \text{if } e_{ij} \text{ is not the first nonzero element and } e_{ik} \text{ is the nonzero element encountered previously.} \end{cases} \quad (3)$$

If e_{ij} is the first nonzero element, then the column location of e_{ij} is specified by "j" with b bits; else, the column location of e_{ij} is specified by "j - k" with b bits.

Step 4:(Encode nonzero neighbors) Traverse the tree whoose root is e_{ij} by dfs until no more nonzero element in the tree is found. During the traversal process, for each nonzero element e_{pq} in the tree, perform the following encoding steps.

(a) Add a prefix "1", indicating that a nonzero child exists.

(b) Append to the prefix the codewords that identify the direction (*sw*,*s*,*se*,*e*) and the value (0,1,2,3) of the element e_{pq}.

(c) If e_{pq} has no child node, then add a postfix "0", indicating that no child node follows e_{pq}.

The effectiveness of the proposed encoding algorithm is shown in Table 4. For formal-style and sung-style Chinese character patterns, the numbers of bits required to encode a rectangle are 5.64 and 4.28, respectively. And for the running-style fonts, the number of bits required to encode a rectangle is 9.18 The fact that more bits required by the running style than the other two styles results from the fact that the running style has smaller rectangles after partitioning. For the formal-style and the sung-style, the improvements of the proposed encoding algorithm were over 60%, comparing with Mohamed and Fahmy's method [5]. For the running style, the improvement is limited by the existence of skewed strokes which result in isolated blocks and small rectangle regions. But the performance is still better than Mohamed and Fahmy's method [5] by 40%.

5. Encoding of contour information

At last, those blocks, which contain stroke contours, in the block map are encoded to achieve a lossless compression result. The values of contour blocks are mixed with black and white; it is impossible for a contour block to contain white pixels only. Our experiments showed that the appearance of the central (contour) block is closely related with the combination pattern of its neighbors. For the purpose of more effective encoding of contour blocks, a context model based on the patterns of blocks is used to exploit such relations.

In the proposed method, we assume that the 8 neighboring blocks of a contour block X are represented by "0" or "1". The combination Y of the 8 neighboring blocks can be defined as follows:

$$Y = \{N_0, N_1, N_2, N_3, N_4, N_5, N_6, N_7\} \quad (4)$$

where $N_i \in \{0,1\}$ and i=0,1,2,3,4,5,6,7. In Equation (4), N_i represents the ith neighbor of the central block. When N_i=0, it means that the corresponding block is white; otherwise, it is black or mixed. Fig. 9 shows the geometric relation between the central block and its 8 neighbors. It is noted that there are 2^8=256 different combinations of the 8 neighboring blocks. Let Y_j represent the jth neighborhood combination. If B_i represents the central block whose index is i (i=1,2,...,16), the probability $p(B_i|Y_j)$ of each distinct central block under each distinct neighborhood combination Y_j can be computed as follows:

$$p(B_i|Y_j) = \frac{N(B_i Y_j)}{N(Y_j)}, \quad (5)$$

where $N(B_iY_j)$ is the number of the situation that block B_i is in the center with neighborhood combination Y_j in an image, and $N(Y_j)$ is the number of the situation that neighborhood combination Y_j occurs in an image. In our experiment, the probability $p(B_i|Y_j)$ does not vary greatly with different input images. Furthermore, static Huffman coding can be used to encode the central block based on the probability value of $p(B_i|Y_j)$. Let l_{ji} be the codeword length of the central block B_i under the combination Y_j of neighbors. The average codeword length L_j for the corresponding combination Y_j can be computed as follows:

$$L_j = \sum_{i=0}^{15} p(B_i \mid Y_j) \times l_{ji}, \text{ where } j = 0, 1, 2, \ldots, 255. \quad (6)$$

For example, in a general document image, when the combination of the neighboring blocks is Y_{31}={0,0,0,1,1,1,1,1} of as shown in Fig. 8, the probability of each distinct block which appears in the neighborhood center are shown in Table 5. The average codeword length L_{31} is 1.65 bits which is much smaller than the codeword length 4 bits which is required to encode each block directly by its index.

The encoding result of the contour information of the above process is put in a file, which we call the context model M. An algorithm is given below to illustrate the proposed contour information encoding method discussed above.

Algorithm 3 Encoding of Contour Information

Step 1: Read in the context model M and the $m \times n$ block-map matrix B which is used previously in rectangle partitioning.

Step 2: For each element b_{ij} in the matrix B, if b_{ij}=2, or b_{ij}=1 and there exists at least one neighboring block of b_{ij} whose value is "0", find out the neighborhood combination Y_j of the central contour block, and perform the following steps.

- (a) If the contour block is B_i, find the corresponding codeword w_{ij} by locating the entry (B_i, Y_j) in the context model M.
- (b) Encode the contour block by the codeword w_{ij}.

Step 3: Stop.

The bit rates for compressing Chinese character patterns are shown in Table 6, from which we see that the rates for the three Chinese font types are 0.253, 0.2334 and 0.2086, respectively. Besides, the average Huffman codeword length of contour blocks is shown in Table 7. The average codeword length of each font is about 1.6 that is 60% smaller than that resulting from encoding each block directly with its index (4 bits). Also, the performance of the proposed method was at least 15% better than those methods used to compress Chinese character patterns. It is worth to note that with Mohamed and Fahmy's method [5] it requires the highest bit rate to compress the running style. A reason is that the running-style patterns contain more skewed strokes that degrade the effectiveness of rectangle partitioning. However, in the proposed method, BMRP reduces the effect of the skewed strokes so that the bit rate of compressing the running style is still close to those required for the other two styles.

The effectiveness of the proposed method in compressing general document images is also examined, and the experimental results are shown in Table 8. The performance of the proposed method is better than other methods except the standard JBIG. But the compression time required by the proposed method is much less than the JBIG. Especially, when compressing the Chinese document image of Fig. 6(d), our result was close to the performance of the JBIG.

6. Conclusions

A new document image compression technique has been proposed in this study. Rectangular region partitioning and contour information encoding are combined to compress Chinese character patterns and document images.

Partitioning the foreground region based on blocks, the BMRP generates less rectangles than other partitioning methods. In addition, a new block-based contour encoding algorithm has also been proposed. Distincting from traditional methods, the proposed algorithm encodes the contour information by the use of the probabilities of different combination of neighboring blocks. Experimental results showed that the proposed technique is not only effective in compressing Chinese character patterns but also in compressing general document images.

The proposed algorithms can be extended using different block sizes rather than 2×2, such as 3×3, 4×4, and 5×5. It is guessed that probabilistic relationships still exist between contour blocks and their neighbors. However, the context model in larger blocks may be much complicated than 2×2 blocks. At last, encoding of rectangles and contour information in our study can be processed in parallel; as a result, the computation time of the proposed algorithm can be reduced further.

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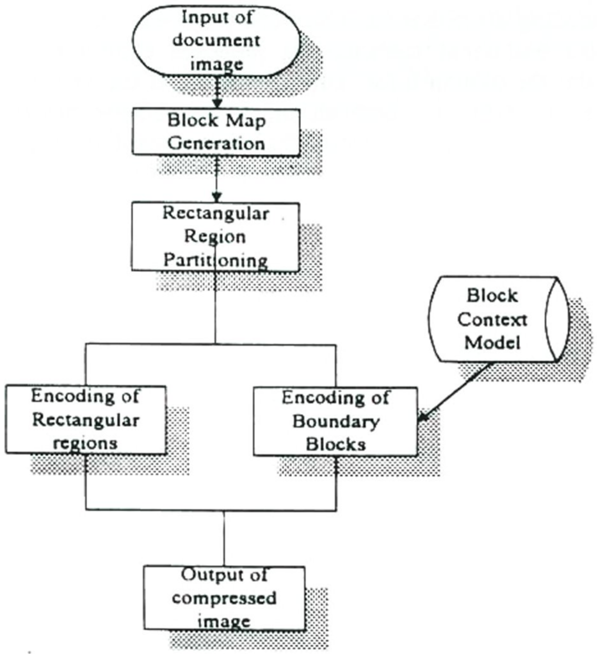


Fig. 2. Flowchart of proposed document image compression method.

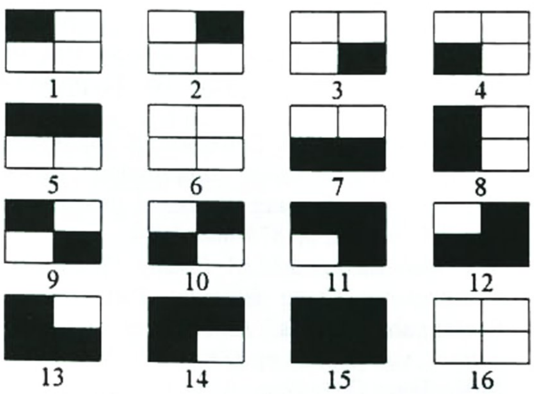


Fig. 1. 16 different kinds of pixel value combinations in each 2 × 2 block.

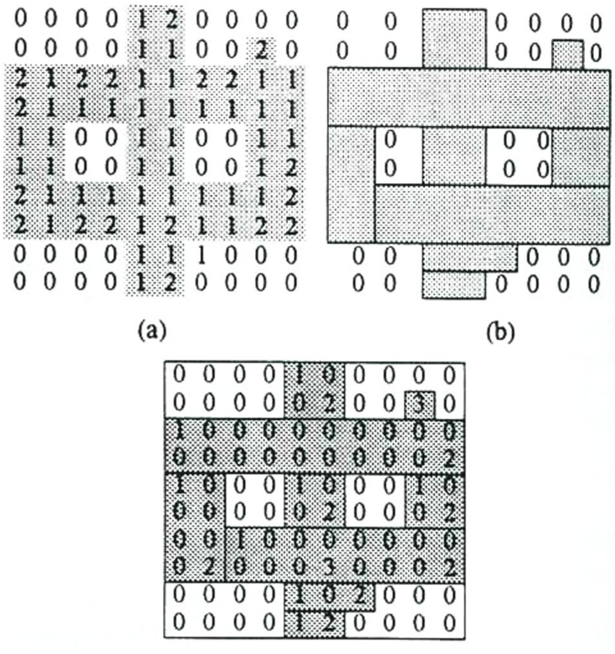


Fig. 4 (a) Block map matrix B of a Chinese character image. (b) Partitioning result of matrix B into nonoverlapping rectangles. (c) Encoding matrix E of block map matrix B.

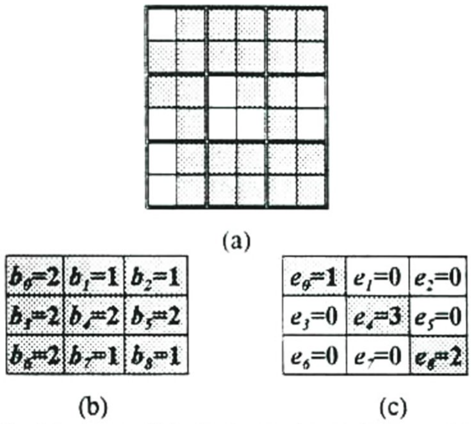


Fig. 3. (a) A small hole in an input image. (b) The corresponding block map of the input image (a). (c) The corresponding E matrix.

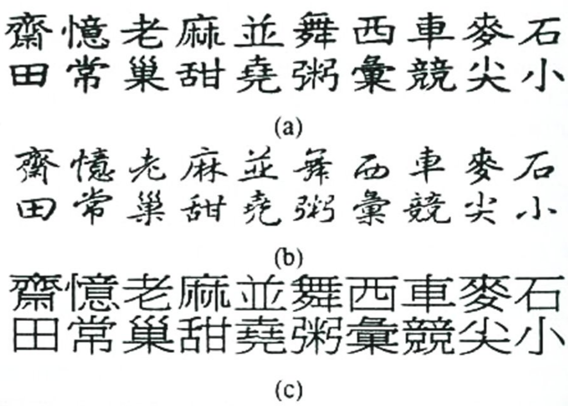


Fig. 5. Test Chinese character patterns. (a) Formal-style font. (b) Running-style font. (c) Sung-style font.

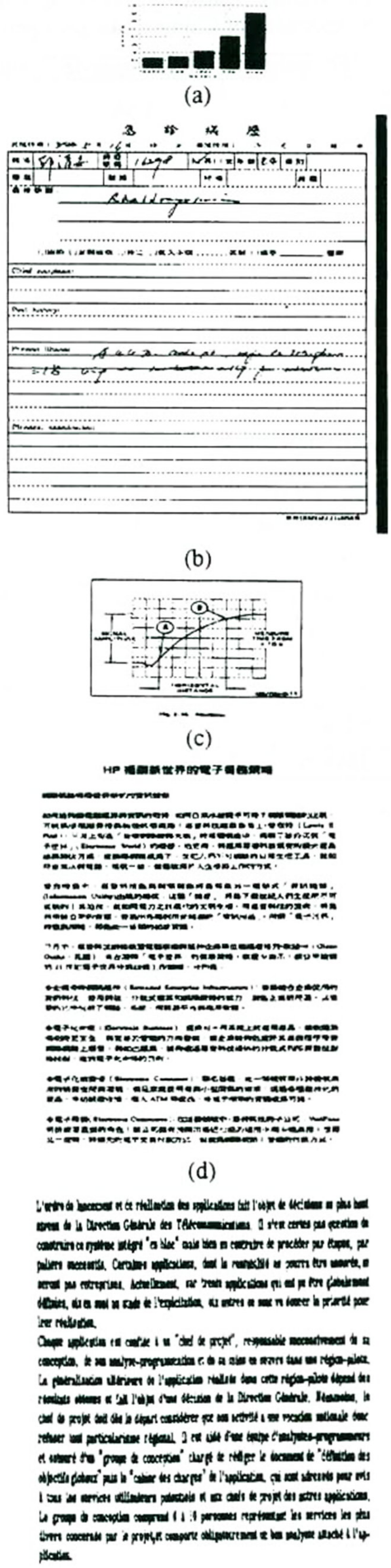
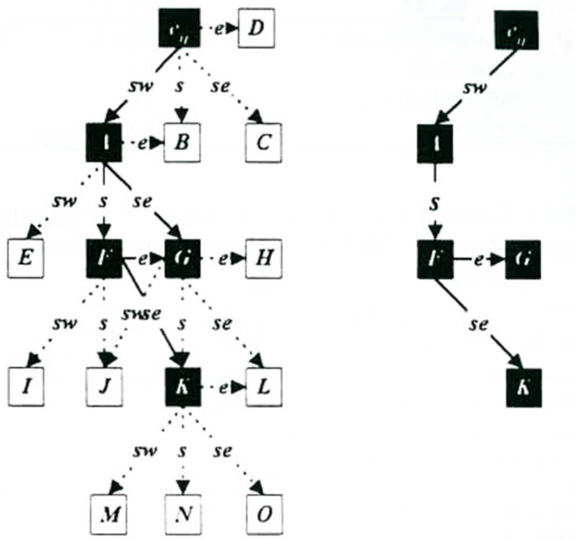


Fig. 6. Test images of different types and sizes. (a) 320×200 (b) 1100×1548 (c) 640×480 (d) 1024×768 (e) 1024×768



(a) All possible branchings from nonzero elements.

(b) The final tree structure.

Fig. 7. An example tree structure in rectangular region encoding.

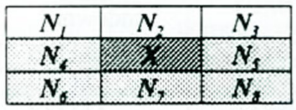


Fig. 8. The combination, Y={0,0,0,1,1,1,1,1}, of the eight neighbors of the center block X.

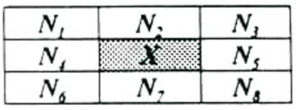


Fig. 9. The center block X and its eight neighbors.

Table 1. Experimental results of proposed BMRP and Mohamed and Fahmy's method (MFM) for partitioning Chinese character patterns into rectangles.

Chinese font	MFM (No. of rectangles/pattern)	BMRP (No. of rectangles/pattern)	Percentage of Improvement
Formal-style	84.8	43.5	48.70%
Running-style	96.7	48.5	49.84%
Sung-style	73.5	36.8	49.93%

Table 2. The codewords for the vertex symbols

Vertex Type	Symbol	Codeword
top left	1	1
bottom right	2	01
isolated or mixed-inner	3	00

Table 3. The codewords for encoding directions

Direction	Codeword
southwestern (sw)	00
southern (s)	01
southeastern (se)	10
eastern (e)	11

Table 4. Experimental results of encoding of rectangular regions (MFM: Mohamed and Fahmy's method).

Chinese font	MFM (bits/rectangle)	Proposed method (bits/rectangle)	Percentage of Improvement
Formal-style	15.49	5.64	63.59%
Running-style	16.57	9.18	44.60%
Sung-style	15.64	4.28	72.63%

Table 5. Huffman codewords for Y_j={0,0,0,1,1,1,1,1}.

Y_j	Bi	$p(Bi\|Y_j)$	Huffman codeword	Huffman codeword length (l_{ij})
31	2	0.000154	111111110	9
31	3	0.0102	11110	5
31	4	0.008017	111110	6
31	6	0.000308	11111110	8
31	7	0.4764	0	1
31	8	0.000771	1111110	7
31	11	0.000154	111111111	9
31	12	0.0213	110	3
31	13	0.0176	1110	4
31	15	0.4653	10	2

Table 6. The bit rates of compression of Chinese character patterns. (MMR: Modified Modified READ (Relative Element Address Designate) coding; 2D RLCWLSP: 2D Run-Length Coding With Line-Segment Prediction; MFM: Mohamed and Fahmy's method)

	Formal-style	Running-style	Sung-style
MMR	0.2810	0.2723	0.2686
2D RLCWLSP	0.2653	0.2448	0.2583
MFM	0.2447	0.2689	0.2106
Proposed method	0.2153	0.2334	0.2089

Table 7. The average Huffman codeword lenghth of compression of Chinese character patterns.

	Formal-style	Running-style	Sung-style
Average Codeword Length (bits)	1.62	1.68	1.54

Table 8. Total number of encoding bits of general document images. (MMR: Modified Modified READ (Relative Element Address Designate) coding; MFM: Mohamed and Fahmy's method)

Test images	MMR	MFM	JBIG	Proposed method
a	31492	28473	18203	22598
b	84716	82673	67172	79131
c	32351	30476	20687	27461
d	264859	236907	148400	181112
e	386906	357179	138213	226424