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Block-run run-length coding of handwriting and bilevel graphics based on quadtree segmentation

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Abstract

An efficient off-line coding scheme for handwriting and bilevel graphics based on quadtree segmentation and block-run run-length coding (RLC) is presented. By segmenting a captured handwriting or graphic image into variable size blocks according to the image activity inside the blocks and run-length coding on a block-run basis, the new scheme is able to achieve higher coding efficiency than the conventional one-dimensional RLC and its bit rate is close to that of on-line dynamographical chain coding. © 1997 Elsevier Science B.V.

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1. Introduction

Handwriting and line drawings are a special subclass of two-level graphic images in which the picture consists of interconnections of thin lines on a contrasting background. Examples are handwritten text, sketches, maps and charts. On-line handwriting and line drawings captured by an electronic writing tablet preserve the temporal information in the data and can be efficiently coded by line following codes such as chain codes. Alternatively, on-line data can be converted to off-line format and coding schemes such as run-length coding (RLC) used in fascimile communication can be applied. Conventional run-length coding of bi-level graphics is based on line-by-line raster scanning and exploits the one-dimensional redundancy associated with alternate runs of 1's and 0's along the scan line. Chain coding encodes the on-line data based on spatial quantisation of the two-dimensional traces into one-dimensional vector chains by translating a coding ring along the traces. Liu and Prasad (1989, 1991) had performed the quantitative analysis and comparison of coding efficiency between off-line RLC and on-line vector chain coding (VCC) for on-line handwritten line drawings, evaluated in terms of per-length coding rate and compression ratio. It was concluded that the on-line coding (VCC) achieved higher coding efficiency than the off-line coding (RLC) if the total length of the lines in a line drawing was within a certain range. This is conceptually true because as an image is covered more and more with handwriting and drawings, off-line run-length coding using binary bitmap may become more efficient than on-line line-following coding which must encode the starting position of each trace and also the overlapped points due to trace crossing. Line-following coding

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also has the limitation of lossless encoding of on-line data only. If one wishes to encode off-line data using line-following codes, the off-line data must be first converted to the on-line format through complicated pre-processing steps including thinning and vectorization.

Converting on-line data to off-line format is quite easy and lossless whereas converting off-line data to on-line format is not a simple task and usually lossy because it involves thinning the off-line data and vectorizing the skeleton information. If the off-line drawings contain many intersection points, the conversion may result in many short traces making the on-line encoding less efficient due to the overhead needed for encoding the starting positions of all traces.

For typical black and white graphic images, most of the long white runs belong to the background which convey no information. Therefore the coding efficiency of RLC can be improved if the background areas were coded more efficiently. Quadtree segmentation has recently become a popular technique for variable block size segmentation in image coding (Yuen et al., 1995) due to its low overhead and simple data structure. In this paper, a new off-line coding scheme based on quadtree segmentation and block-run RLC is proposed for coding handwriting and bilevel graphics which have been converted to off-line format. Compared to the conventional ITU recommended one-dimensional RLC (ITU, 1988), the proposed scheme has better coding performance and its bit rate is close to that of on-line chain coding. Since the proposed scheme is on an off-line coding basis, it is able to achieve lossless encoding on both on-line and off-line handwriting and line drawings while the dynamographical chain coding is only capable of lossless encoding of on-line data.

In chain coding schemes, standard chain coding (SCC) encodes a trace into a chain of absolute vectors with $I[\log_2 8n]$ bits using a coding ring of $M = 8n$ nodes, where $I[x]$ denotes the smallest integer equal to or greater than x, and $n = 1, 2, 3, \ldots$. Differential chain coding (DCC) developed at Delft University of Technology for telegraphics applications (Arnbak et al., 1989) is a more efficient scheme by exploiting the correlation between successive vectors, based on the statistical properties of vector difference for smooth handwriting and line drawings. Relative vectors with fewer bits are defined when the following vector differs from the previous vector with zero or one vector node, thus reducing the coding rate. Recently, lossy differential chain coding schemes such as fixed-length differential chain coding (FL-DCC) (Yuen and Hanzo, 1995) and DM-like differential chain coding (DM-DCC) (Yuen, 1996) were introduced for even higher coding efficiency and better transmission error immunity by quantizing the differential vectors in the vector chains into adaptively defined fixed-length codes and one-bit delta vectors, respectively.

We assume black-and-white handwriting and line drawings such that black lines are drawn on a white background. The on-line handwriting data were captured using an electronic writing tablet which outputs the x, y co-ordinates of the writing pen tip. In order to apply the off-line coding scheme to the on-line handwriting data, a transcoding algorithm was used to convert the on-line handwriting data into the off-line raster scanning bit pattern. A two-dimensional bilevel buffer was defined in which pixels corresponding to the trace points were turned on (black) while the remaining pixels corresponding to the background were off (white). Since the tablet did not produce the thickness information, the transcoded handwritten traces were assumed to have one-pixel width. Aimed for higher source coding efficiency, the proposed coding scheme encoded data on an off-line basis without the temporal information which was lost in the transcoding process.

2. Quadtree segmentation and block-run RLC

A quadtree constitutes a hierachical data structure which can be used to efficiently decompose an image into variable size blocks according to the image activity inside the blocks and each segmented block is coded at a different rate according to its level of detail. The quadtree code specifies the size and location of each block. Each node of the quadtree, unless it is terminated, generates four child nodes and a terminated node becomes a leaf. Every node corresponds to a subblock, whose size and location is determined by its position in the quadtree. In the proposed scheme, a three-level quadtree segmentation is implemented on the graphic image to locate the low-detail background blocks and separate the high-detail information-carrying blocks. For graphic images of

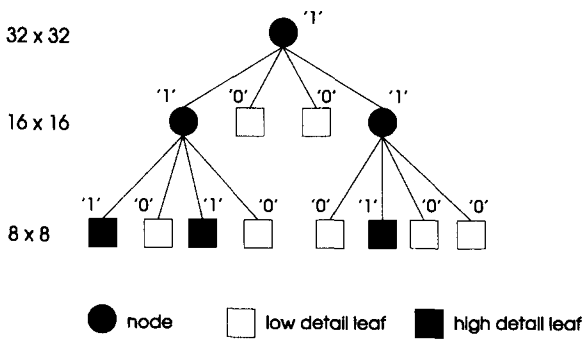

Fig. 1. 3-level quadtree structure.

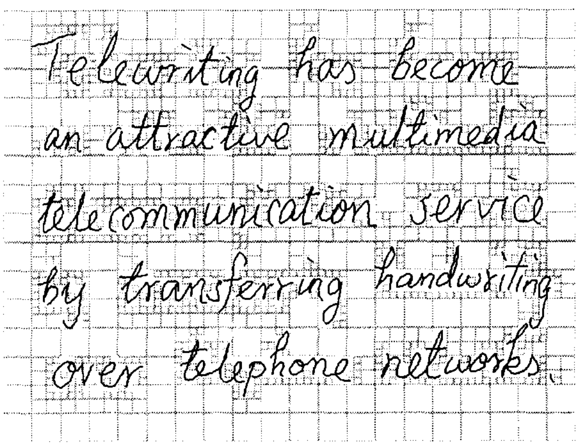

Fig. 2. Quadtree segmented *English script*.

640 × 480 pixels, the largest block size is 32 × 32, the intermediate block size is 16 × 16 and the smallest block size is 8 × 8. Initially, the input image is uniformly segmented into blocks of size 32 × 32 and each block is examined for its activity. If a block contains all white pixels with no black pixels, it will be classified as a background leaf block and a 1-bit quadtree code "0" is generated. Otherwise, it will be further split into four child blocks of 16 × 16 size, generating the quadtree code "1". This splitting process is continued until the smallest block size 8 × 8 is reached and each block is marked by the code "0" or "1" according to the activity inside the block. In this way, all the high-detail information-carrying blocks can be identified from the input image. Fig. 1 illustrates the 3-level quadtree structure along with the quadtree codes for each node or leaf.

All variable size background blocks are encoded using just 1-bit quadtree code and no further encoding is required. Fig. 2 shows the quadtree segmented *English script* while Fig. 3 displays the quadtree segmented *Map*, with the low-detail background blocks of three block sizes marked by their boundary. It can be seen that the quadtree segmentation has effectively located the background blocks especially along the edges of the input image, and identified the high-detail information-carrying blocks. Hence, the proposed quadtree decomposition may be useful in segmenting handwriting for off-line recognition application.

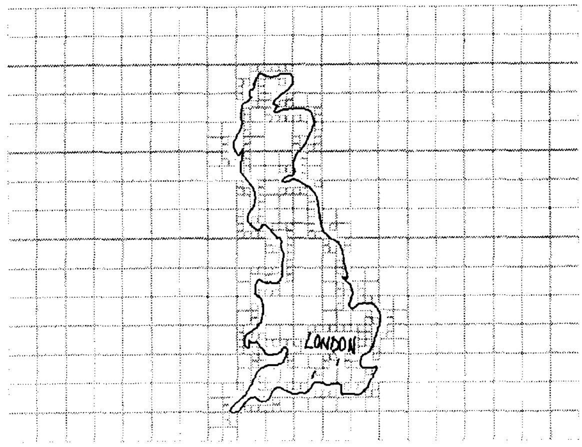

Fig. 3. Quadtree segmented *Map*.

In order to achieve even higher efficiency in run-length encoding of the high-detail information-carrying leaf blocks, we grouped them together by scanning them into a long one-dimensional (1-D) block-run in order to have long pixel runs. The bit stream formed by raster scanning of each block in the block-run was then coded using the variable length RLC. Note that the ITU recommended 1-D modified Huffman code was optimized using CCITT standard facsimile test documents with a normal resolution of 1728 × 1188 pixels or high resolution of 1728 × 2376 pixels. It is not the optimal variable length RLC for the transcoded handwritten line drawings which consist of thin lines only. Hence the proposed scheme will be more efficient if the width of traces is more than one pixel.

3. Bit rate for graphic image

In order to measure the coding efficiency and have a realistic comparison for the proposed coding scheme,

Table 1
Bit rates of off-line and on-line coding schemes for various on-line handwriting and line drawings

Handwriting	ITU RLC	Proposed scheme	SCC	DCC	FL-DCC
Bilingual script	0.2796	0.1988	0.1692	0.1337	0.1246
Chinese script	0.2100	0.1386	0.1274	0.1195	0.0992
English script	0.2044	0.1249	0.0940	0.0748	0.0665
Drawing	0.1394	0.0855	0.0589	0.0483	0.0404
Map	0.0806	0.0260	0.0162	0.0138	0.0113

ITU 1-D RLC and various chain coding schemes, we define the bit rate r in bits per pixel of a coding scheme for a graphic image of $M \times N$ pixels as

$$r = \frac{b}{M \cdot N}, \tag{1}$$

where b is the total number of bits required by the corresponding coding scheme to encode the whole graphic image. For on-line chain coding schemes, b is given by (Yuen, 1996)

$$b = \sum_{i=1}^{m} (PD + X_0 + Y_0 + V_i + PU), \tag{2}$$

where m is the total number of traces, PD is the number of bits for the pen-down, X_0 and Y_0 are the numbers of bits for the x- and y-coordinates of the trace origin, respectively, V_i is the number of bits for the vector chain in trace i, and PU is the number of bits for the pen-up. For the off-line coding schemes, b consists of quadtree structure bits and RLC bits in the proposed scheme while b represents only RLC bits in ITU recommended 1-D RLC.

The size of the handwriting and line drawings used in our implementation is 640×480 pixels for a VGA resolution. The bit rate required for a particular handwriting or line drawing depends on the actual writing density. The more writing or drawing on the same area, the higher the bit rate. Bit rate r in Eq. (1) is different from the conventional coding rate used in chain coding (Neuhoff and Castor, 1985), which was defined as the number of bits per unit length of the trace segment. The per-length coding rate for chain codes is an image activity independent measure because it has been normalized by the trace length and the overhead bits such as pen-down and pen-up are not counted. In contrast, the bit rate r defined in Eq. (1) is image activity dependent which means lower bit rate for a lower activity image, owing to the higher amount of redundancy in the low activity area that can be exploited by an efficient coding scheme.

Table 2
Bit rates of off-line coding schemes for off-line CCITT test documents

CCITT document number	ITU RLC	Proposed scheme
1	0.0760	0.0686
2	0.0682	0.0523
3	0.1299	0.1243
4	0.2256	0.2426
5	0.1384	0.1291
6	0.1032	0.0801
7	0.2162	0.2021
8	0.1249	0.1029

4. Experimental results

To evaluate the performance of the proposed coding scheme, a range of on-line handwriting and line drawing images including a bilingual script, a Chinese script, an English script, a drawing and a map were captured by an electronic writing tablet and coded using the proposed scheme, ITU recommended 1-D RLC scheme, SCC, DCC and FL-DCC (with a chain coding resolution of $M = 8$, $\tau = 1$), respectively. The on-line data was converted to off-line format before applying the off-line coding schemes. Table 1 shows results of bit rate in bits per pixel of the off-line and on-line coding schemes for on-line handwriting and line drawings. It can be seen that the proposed scheme outperforms the ITU 1-D RLC by achieving a lower bit rate for all the handwriting and line drawings. Its bit rate performance approaches that of SCC when the image activity becomes higher in the *Bilingual script* case, or when handwritten traces have shorter lengths in the *Chinese script* case. On the other hand, DCC and the lossy FL-DCC achieved even lower bit rates than SCC. The proposed coding scheme was also implemented on the eight CCITT standard test documents of high resolution 1728×2376 pixels for assessing the performance on facsimile-type bi-level graphic documents, and the results are shown in Table 2. It is clear that the proposed scheme outperforms the ITU 1-D

RLC for most of CCITT test documents as well.

5. Conclusions

An efficient off-line coding scheme for handwriting and bi-level graphics based on quadtree segmentation and block-run RLC has been presented. Quadtree segmentation separated the low-detail image areas from the high-detail areas which were coded by efficient RLC on a block-run basis. The proposed coding scheme achieved higher coding efficiency than the conventional ITU recommended one-dimensional RLC on handwriting and line drawings as well as on facsimile-type documents while its performance is close to that of on-line chain coding.

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