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Segmentation-based object-oriented image compression scheme

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Abstract

A new object-oriented still image compression scheme, based on a region segmentation technique, is presented in the paper. Segmentation in the proposed scheme is done according to a criterion of pixel intensity (for grayscale images) or criterion of index into the palette of colors (for color images). A high compression ratio of this method is achieved by rejecting the regions of the smallest area (according to a given threshold criterion), and by the coding scheme of applied two-stage algorithm for contour compression. Stages of contour compression and coding refer to the edges of remaining separable and homogeneous regions, which are extracted from an input image during the segmentation process.

Keywords: object-oriented image coding, region segmentation, contour extraction and compression, transform coding.

Schemat obiektowo zorientowanej kompresji obrazów z wykorzystaniem segmentacji

Streszczenie

W artykule przedstawiono propozycję nowego schematu obiektowo zorientowanej kompresji obrazów realizowanego w oparciu o metodę segmentacji obszarowej. Segmentacja w proponowanym schemacie przeprowadzana jest w oparciu o kryterium poziomu szarości (dla obrazów w skali szarości) lub o kryterium indeksu koloru w palecie barw (dla obrazów kolorowych). Uzyskane w drodze segmentacji jednorodne i homogeniczne obszary są następnie poddawane procedurze SSPCE w celu znalezienia konturów opisujących ich krawędzie brzegowe. Wysoki stopień kompresji obrazu w proponowanej metodzie uzyskiwany jest przede wszystkim w efekcie zastosowania, zaproponowanego również przez autora tej pracy, dwustopniowego schematu kodowania ww. konturów, który łączy w sobie zmodyfikowany algorytm kodowania transformatowego z wygładzającym charakterem wybranej, przestrzennej metody aproksymacji konturów. Dodatkowo, na wartość tego współczynnika wpływa, przeprowadzane we wstępnym etapie, odrzucanie, zgodnie z przyjętym kryterium progowym, obszarów o najmniejszych polach powierzchni.

Słowa kluczowe: obiektowo zorientowana kompresja obrazów, segmentacja obszarowa, ekstrakcja i kompresja konturów, kodowanie trans formatowe.

1. Introduction

The most well-known and popular methods for image compression treat an image as an array of unrelated pixels. Transform image compression methods for instance converts image into the unrecognizable form of spectrum coefficients. However, there is also another approach, where image compression is done according to its content. In general, such an approach consists of segmentation techniques [1], which decompose the image into the separable and homogeneous segments (regions) that collectively cover the entire image. Decomposition can be performed according to many different criterions of homogeneity, e.g. colour, intensity or texture. Segmentation-based image compression methods are classified as object-oriented methods, sometimes also referred to as second-generation image-coding techniques [2].

A new scheme of such an object-oriented image compression method, based on a region segmentation technique, is presented in the paper. The segmentation stage is followed by other important tasks, which are contour extraction and contour compression. Contour extraction, applied to extracted regions, is done using the SSPCE method [3]. Contour compression is performed with use of a very effective two-stage algorithm which incorporates techniques of transform coding and spatial contour approximation.

The presented scheme of image compression may have a wide application range, especially in thermovision, dynamic analysis by fast image registration and image transmission over the network.

2. The SSPCE method

There are two main classes of contour extraction methods: the Object Contour Following (OCF) and the Multiple Step Contour Extraction (MSCE) . The Single Step Parallel Contour Extraction - SSPCE method [3] as well as the gradient edge detection methods [4] belong to the MSCE class. The SSPCE algorithm uses a 3x3 pixels window structure to check if a central pixel P*i,j* belongs to the traced contour. A decision on this subject is taken according to values of 8 pixels surrounding pixel P*i,j* and predefined identification rules. The number of analyzed pixels and the form of applied identification rules depend on a chosen connectivity scheme between the pixels [3]. The 8-directional Freeman chain coding system [5], related to the used 8-connectivity scheme, is illustrated in Fig. 1.

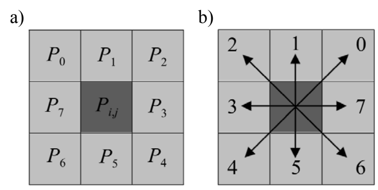

Fig. 1. Numbering pixels in the 3x3 pixels window structure (a) and the Freeman Chain Code system of Eight Directions (b)
Rys. 1. Numerowanie pikseli w oknie o rozmiarze 3x3 (a) i 8-kierunkowy kod łańcuchowy Freemana (b)

The applied identification rules can be described by the following formulas:

$$\mathbf{B}(i,j)=C_k \quad \text{if} \quad \left\{ \mathrm{P}(i,j)\cap \mathrm{P}_{3-k}\cap\left(\mathrm{P}_{4-k}\cup \mathrm{P}_{5-k}\right)\cap \overline{\mathrm{P}_{1-k}}\cap \overline{\mathrm{P}_{2-k}} \right\}=1$$
$$\text{for } k=0,2,4 \text{ i } 6; \tag{1}$$

$$\mathbf{B}(i,j)=C_k \quad \text{if} \quad \left\{ \mathrm{P}(i,j)\cap \mathrm{P}_{4-k}\cap \mathrm{P}_{3-k}\cap \overline{\mathrm{P}_{2-k}} \right\}=1$$
$$\text{for } k=1,3,5 \text{ i } 7; \tag{2}$$

where: **B**(i, j) – coded edge direction; $C_k = 2^k$ – code of edge direction for k = 0, 1, 2, 3, 4, 5, 6, 7; P(i, j) – tested pixel; P_k – pixel from direct neighborhood of P(i, j).

3. The two-stage contour compression scheme

The contour compression scheme [6] used in the proposed object-oriented image coding method is based on a modified transform coding technique which is combined with a selected spatial contour approximation algorithm.

The main goal of the transform coding applied at the first stage of the described scheme is to achieve the compression ratio as high as possible. Normalizing the input signals (e.g. one-dimensional vectors representing the input contour coordinates in the Cartesian coordinate system – each of the input vectors is normalized and processed further individually) is the first step of the implemented transform coding method. Normalizing is done according to the following equation:

$$x_{norm} = \sum_{i=0}^{D-1} \left(x_i - x_{ave} \right), \tag{3}$$

where: x_{ave} – average value of the input signal x; D – length of the input signal.

The vector x_{norm} is divided into sub-vectors of the length M. Each of these sub-vectors is then processed using chosen transform (according to its very good piecewise linear approximation abilities, the PWL transform [7] was selected), which produces $D/M \times M$ array of spectrum coefficients. In the next step, the array of spectrum coefficients is transposed, making the coefficients grouped according to their position. The vector of variances, calculated for each row of the grouped coefficients array, is created then. This vector is required for the normalization process, which lets the same quantizer be used for data series with different variances. The vector of variances is also used by the Integer Bit Allocation procedure to create the sequence of bit allocation. The implemented Integer Bit Allocation procedure is as follows:

step 1. Initialization: $b_k = 0$, $d_k = \sigma_k^2$, $z = 0$, for $k = 1,2,\ldots, M$;

step 2. while $\left(z < M \cdot a \right)$:
- finding position k^* at which d_k is maximal;
- allocating one bit to the k^*-th position:
  $b_{k^*} = b_{k^*} + 1, \quad d_{k^*} = d_{k^*} / 2$;
- incrementing z;

step 3. correction of b_k in respect to the variability of v_k:
- finding p_k;
- finding bb_k: $bb_k = \log_2 \left(p_k \right) / \log_2 2$;
- if $b_k > bb_k$ than $b_k = bb_k$.

where: M x n – size of the array of grouped coefficients ($n = D/M$); v_k – k-th row of the array of grouped spectrum coefficients, $k = 1,2,\ldots, M$; σ_k^2 – variance for a given v_k vector; a – mean number of bits allocated for the quantized vector; b_k – number of bits allocated to v_k; z – total number of allocated bits; p_k – number of different values in v_k; bb_k – maximum number of bits that can be allocated to v_k.

The vector of bit allocation determines quantization of v_k vectors. Because Gaussian or Laplacian probability density functions had been expected, the optimal Lloyd-Max Quantizer [8] was applied. Such an approach as described above is especially efficient for signals with uniformly distributed values – e.g. contours in the Cartesian representation.

The quantized values, at the final step of the implemented transform coding method, are coded and stored (or transmitted). Coded information contains:
- value x_{ave} (in fixed-point representation),
- value $log_2 D/M$, where D/M indicates number of rows of the array of spectrum coefficients;
- vector pv with binary encoded information of positions of transmitted (1) or no (0) v_k vectors;
- variances of these v_k vectors for which $pv_k = 1$ (in floating-point representation);
- vectors with differentially encoded (using the Adaptive Huffman coding) of quantized values and their indices.

The purpose of the second stage of the contour compression scheme described in this section is to reduce the distortion, which is introduced into the processed contours by the quantization step of the implemented transform coding procedure, to the acceptable level. The contour approximation method which was finally selected to achieve this goal, due to its very good smoothing abilities, is the tangent method [9].

4. The proposed object-oriented image coding scheme

The proposed object-oriented image coding scheme is based on a simple region segmentation technique which is done according to the pixel intensity (for grayscale images) or to indices into the colour palette (for colour images). This segmentation technique decomposes the input image into the separated regions which, in general, are not entirely integral but consist of a certain number of uniform fields. During the pre-processing step, these fields are treated as holes inside the extracted regions and filled. A set of separated homogeneous regions obtained in this way is sorted finally in descending order according to their areas, so the region with the greatest area (with the greatest number of pixels included), further referred to as the background of a processed image, receives number 1. The region of the biggest "mass" is then extracted and separated from the background. This ends the first, decomposing step of the proposed scheme. The palette of colours (or array of intensities) recognized for each of the extracted regions is created and sorted simultaneously. Some selected illustrations referred to the first step of the proposed scheme are depicted in Fig. 2.

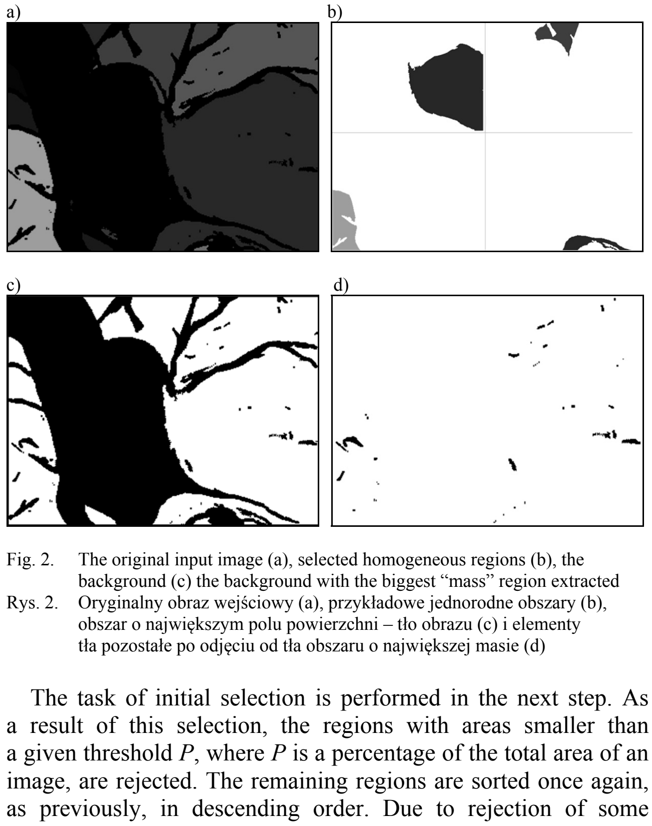

Fig. 2. The original input image (a), selected homogeneous regions (b), the background (c) the background with the biggest "mass" region extracted

Rys. 2. Oryginalny obraz wejściowy (a), przykładowe jednorodne obszary (b), obszar o największym polu powierzchni – tło obrazu (c) i elementy tła pozostałe po odjęciu od tła obszaru o największej masie (d)

The task of initial selection is performed in the next step. As a result of this selection, the regions with areas smaller than a given threshold P, where P is a percentage of the total area of an image, are rejected. The remaining regions are sorted once again, as previously, in descending order. Due to rejection of some regions, the colour palette needs to be rebuilt.

The next step of the proposed compression scheme includes procedures of contour extraction and compression. Each of the separated regions is like a "white" object (all pixels are equal to 1) which added to a "black" mask (an image of an input image size and all pixels equal to 0) creates a binary image. The contour of this "white" object is extracted using the SSPCE [3] procedure. The two-stage contour compression scheme is used then to reduce the bit rate required for their transmission or storage. Finally, to each of the extracted and compressed contours, the corresponding index in the color palette is assigned.

The step of contour extraction and compression is illustrated in Fig. 3.

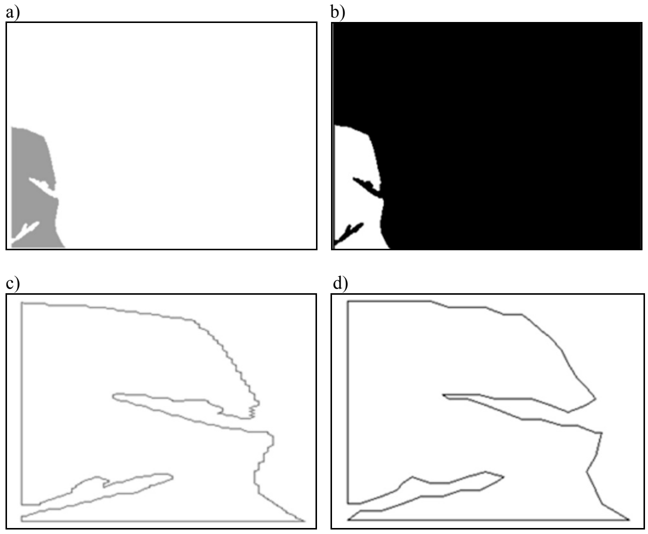

Fig. 3. An exemplar of homogeneous region (a), a binary image created by putting the region a on the "black" mask (b), contour extracted from image b (c) and reconstructed contour after compression (d)

Rys. 3. Przykładowy, jednorodny obszar (a), obraz binarny powstały poprzez naniesienie obszaru a na czarne tło (b), kontur wyekstrakowany z obrazu b (c) i kontur odtworzony po kompresji (d)

Because, there is no possibility to predict the distortion which is introduced into the processed contour by the two-stage contour compression scheme, a feedback procedure has been organized. This feedback procedure recalls the two-stage contour compression scheme till the introduced distortion exceeds the assumed level. The compressed contours are coded in the way described in Section 3. In addition, the coded stored (or transmitted) information is completed with the vector of intensity levels (or values of color components) and the size of the original input image.

The reconstruction step starts from initializing an "empty" image array with size and background colour of the original input image. The regions, which are reconstructed according to the decoded contours and related to them intensity levels or values of related colours (information about intensities or colours is taken from the simultaneously reconstructed colour palette), are consecutively applied to the initial "empty" image.

5. Applied measures and obtained results

Analysis of compression abilities (including quality of reconstruction) of the proposed object-oriented image coding scheme has been performed using the following measures:

– compression ratio

$$\eta = \frac{(b-c)\cdot 100\%}{b}, \tag{4}$$

where: b – number of bits required for the input image; c – number of bits of coded information.

– Peak Signal-to-Noise Ratio (PSNR)

$$PSNR = -10 \cdot \log\left(\frac{\sum_i \varepsilon_i^2}{N \cdot d^2}\right), \tag{5}$$

where: ε_i – difference between values of i pixels in original input image and image after reconstruction; N – total number of pixels in processed image; d – maximum value of pixels.

The selected results of using the proposed object-oriented image coding scheme are presented in Fig. 4.

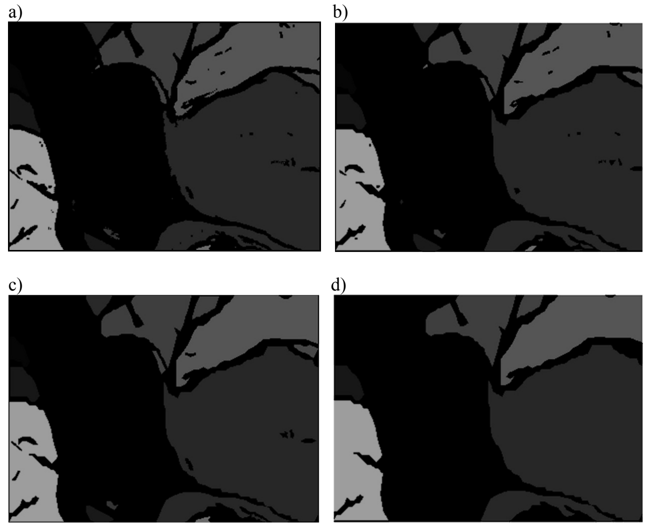

Fig. 4. Processed image (a) and reconstructed images after compression performed for different values of the threshold P: b) $P = 0{,}01\%$; $\eta = 95{,}09\%$; PSNR = 30,98dB, c) $P = 0{,}06\%$; $\eta = 96{,}13\%$; PSNR = 28,34dB, d) $P = 1{,}00\%$; $\eta = 98{,}29\%$; PSNR = 25,84dB

Rys. 4. Obraz poddawany kodowaniu (a) i obrazy po kompresji uzyskane dla różnych wartości progu P: b) $P = 0{,}01\%$; $\eta = 95{,}09\%$; PSNR = 30,98dB, c) $P = 0{,}06\%$; $\eta = 96{,}13\%$; PSNR = 28,34dB, d) $P = 1{,}00\%$; $\eta = 98{,}29\%$; PSNR = 25,84dB

6. Conclusions

A new object-oriented image compression scheme is presented in the paper. The proposed scheme is based on a region segmentation technique which is done according to pixel intensities (or colours in the colour palette). The step subsequent to segmentation incorporates the specialized two-stage procedure (introduced by the same author) for contour compression. This procedure combines a modified transform coding technique and the tangent method of spatial contour approximation. High compression properties of the implemented transform coding scheme and good filtering abilities of the tangent method allow achieving the high compression ratio as well as satisfactory quality of reconstruction in the proposed image coding scheme. The presented object-oriented technique is especially effective for vector-based images. Fig. 4 shows that the compression ratio achieved in the proposed scheme for this kind of graphics can be even greater than 95%.

7. References

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