Вісник Тернопільського національного технічного університету
Scientific Journal of the Ternopil National Technical University
2018, № 3 (91)
ISSN 2522-4433. Web: **visnyk.tntu.edu.ua**

INSTRUMENT-MAKING AND INFORMATION-MEASURING SYSTEMS

ПРИЛАДОБУДУВАННЯ ТА ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНІ СИСТЕМИ

UDC 004.042

SELECTION OF THE EFFICIENT VIDEO DATA PROCESSING STRATEGY BASED ON THE ANALYSIS OF STATISTICAL DIGITAL IMAGES CHARACTERISTICS

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Summary. *Technique of the video data redundancy estimation during the images processing in the real time is offered. The ways of reducing the incoming data while processing digital images are considered. An effective approach for solving the recognition problems while analyzing dynamic video information or for background recording when the portion of data about the color of digital image pixels passes from frame to frame without changes is suggested. The expediency of the image foldover has been analyzed in order to reduce the redundancy of the information presented in it by replacing the operation of information storage about the pixel color by calculating operations or combining the pixels portion under one colour attribute. The approach c motivated by the evaluations of the statistical digital image characteristics is considered.*

Key words: *image identification, digital image redundancy, maximum uncertainty of stohastic data array, conditional data array entropy.*

Received 29.08.2018

Statement of the problem. Video systems in real time mode use video cameras with preset parameters of reading the video information from the sensors. This results in significant redundancy of the image recording and complicates its processing as the object identification system deals with high-resolution ability and as result with the processing of large datasets. There are several ways of solving the problem of large data sets in the real time mode. Usually, the problem of processing large arrays is solved by representing certain parts of the image with some averaged values especially when it concerns the identification algorithms in the real time mode.

Analysis of the available investigations and publications. In the available methods the reduction of the input information occurs due to the cluster mapping of pixels with similar colour parameters onto super pixels with mean colour and position according to certain clustering rules [1 – 5].

Algorithms using deep convolution neural networks often rely on sets of parallel processors for the distribution of calculations [6, 7].

Another approach is to create algorithms designed on the principles of visual preception, which analyze pixels along a certain route, fixed by the movements of the observer's eyes, forming characteristic image signs [8, 9].

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Methods of adaptive binarization for reduction of the information content during processing are known as well [10]. Their main idea is to compare the pixel colour value with the mean arithmetic value of the neighboring pixels colours and further application of the data integral representation for a particular cluster.

The objective of the paper is to evaluate the redundancy of digital images and to construct algorithms of their reduction at the initial stage of processing.

One way or another, it should be noted that the basic information about the image from the digital video camera is characterized by considerable redundancy. Especially when it concerns such objects identification as alphabet characters, road signs, etc. This means that the amount of data on informative attributes in object identification can be reduced, and data processing can be optimized for the required number of computations. Along with the above mentioned ways of reducing the information about a digital image when its recording or transmission without loss of its characteristic features, we offer the approach based on quantitative estimation of digital images redundancy and algorithms of their reduction at the initial stage of processing.

Entropy as the information measure of the digital image. Suppose $(m \times n)$ is the size of the image in pixels, q is the size of the discrete colour scale. Then the maximum uncertainty of one frame, when the colour of each pixel with equal probability can be represented by one of the colors of the scale, we determine as follows

$$H_{\max} = mn \log_2 q \quad (1)$$

However, in the images of the particular object between the pixels colors there is a certain statistical dependence defined by the image nature, size, general background and video message framing frequency. Our aim is to use this fact in order to reduce the amount of input data while processing the image. To evaluate the real information uncertainty of the colour distribution in the image, let us calculate the probability of the availability of each color in the analyzed image palette

$$p_{C_i} = \frac{n_{C_i}}{q},$$

where n_{C_i} is the number of pixels with colour c_i in the given image.

Thus, we determine the real informational uncertainty of the colour distribution in the image

$$H = -mn \sum_{i=1}^{q} p_{C_i} \log_2 p_{C_i} \quad (2)$$

The image information redundancy is calculated as follows

$$R = 1 - \frac{H}{H_{\max}} \quad (3)$$

For the colour image of 32 × 32 pixels in 96 colours, shown in Fig. 1 a the maximum entropy value is 6712 bits, and actual value of the information uncertainty is 5923 bits, and for the image in 57 colours in Fig. 1 b is 6176 bits and 5398 bits relatively.

This means that from the point of view of informative content, the portion of data can be not taken into account without losing the content of the images under consideration. The amount of these data in accordance with the quantitative estimations of the redundancy of these images by the formula (3) should not exceed 8% of the total amount in Fig. 1 a and 10% in Fig. 1 b.

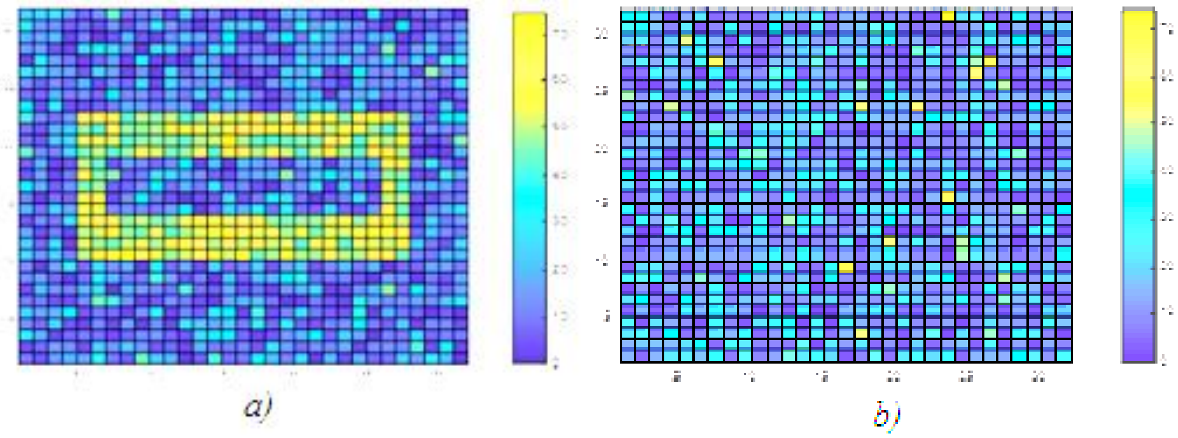

Figure 1. Pixel images and degree of their information uncertainty

Ways of partial elimination of information redundancy. By formula (3), we can estimate the maximum amount of primary data about pixel colors that may be not taken into account while processing images without the loss of their information kernel. The question is when and what data can be neglected. The answer can be found among the statistical characteristics of the data array about pixels colours in the given image.

Suppose P – is the matrix of dimension probabilities (qxq). Its elements p_{ij} denote the probability that the colour pixel c_j follows the colour pixel c_i, like in the image segment shown in Fig. 2 a. It should be noted that when the statistical dependence on colors extends to k sequenced pixels, matrix P dimension is (qxqxk) or (qxqxkxl), and its elements p_{ijm} or p_{ijmn} have the same value like in the previous case as it is shown in Fig. 2 b and Fig. 2 c.

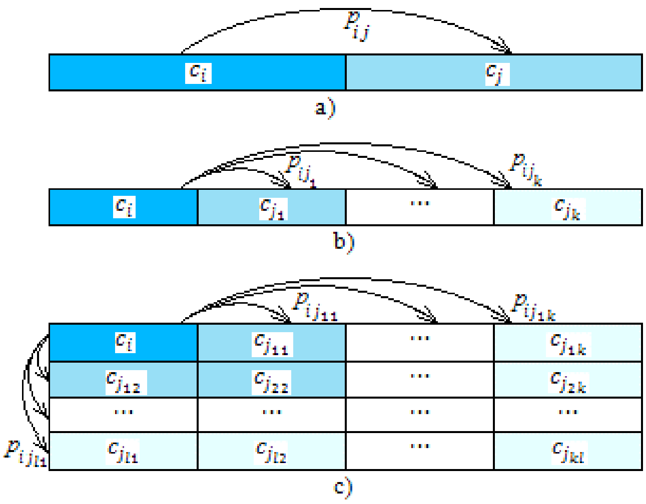

Figure 2. Use of the static dependence on the colour of adjacent pixels

Besides, the statistical dependence of pixel colour parameters in sequenced video frames can also be taken into account. In order to simplify the presentation, let's turn back to the first version, when P is the probability matrix (qxq), and its elements p_{ij} mean the probability that the pixel colour c_j follows after pixel c_i.

The first conclusion that we can make follows from the form of the matrix *P*: if the largest values in the *i*-th row take the elements p_{ii} in the matrix main diagonal – there is a tendency to store the previous colour value in the next pixel. That is, without the loss of the image characteristic features, we can save the colour attribute of one pixel, automatically assigning the following the same value.

The second conclusion is that the quantitative assessment of the information uncertainty degree regarding the colour of pixels pairs registered at the same values can be estimated by the average entropy value

$$H_{av}(j,i) = H(j,i)/2 \,, \tag{4}$$

where $H(j,i) = -\sum_{i=1}^{q}\sum_{j=1}^{q} p_{ij}\log_2 p_{ij}$.

The third conclusion is that we can also calculate the value of conditional entropy H(j|i), which is the estimation of the information uncertainty degree concerning color if the value c_i is known

$$H\ (j\,|\,i) = H(j,i) - H(i) \,, \tag{5}$$

where $H(i) = -\sum_{i=1}^{q} p_{c_i}\log_2 p_{c_i}$.

Or otherwise, after determining the probabilities $p\,(c_j, c_i)$ via the statistical analysis of the data on the digital image, *H (j | i)* can be calculated by the following steps

$$H(j\,|\,i) = \sum_{i=1}^{q} p\,(c_i) H\ (j\,|\,c_i)\,, \tag{6}$$

where $H\ (j\,|\,c_i) = -\sum_{i=1}^{q} p\,(c_j\,|\,c_i)\log_2 p\,(c_j\,|\,c_i)$.

And taking into account that

$$p\,(c_j\,|\,c_i) = \frac{p\,(c_j, c_i)}{p\,(c_i)}\,,$$

$$H\ (j\,|\,i) = -\sum_{i=1}^{q} p\,(c_i)\sum_{j=1}^{q}\frac{p\,(c_j, c_i)}{p\,(c_i)}\log_2\frac{p\,(c_j, c_i)}{p\,(c_i)}$$

or

$$H\ (j\,|\,i) = -\sum_{i=1}^{q}\sum_{j=1}^{q} p\,(c_j, c_i)\log_2\frac{p\,(c_j, c_i)}{p\,(c_i)}\,. \tag{7}$$

After comparing the values obtained by formulas (5) and (7), provided that

$$H\,(j \mid i) < H_{av}\,(j,i) \tag{8}$$

we can look for ways of exclusion $H\,(j \mid i)$ from $H\,(j)$ depending on the image nature.

The offered approach seems to be effective in solving the identification problems while analyzing dynamic video information or for background fixing when the portion of data about the colour of pixels of the digital image passes from frame to frame without changes.

Experimental investigations. Thus, the strategy of transforming the image during its processing in order to reduce the amount of data will depend on the relationship between the entropy values defined in (1 – 7).

The offered algorithm consists of the following stages:

a) based on the size of the digital image in pixels, by formula (1) we calculate H_{max} – the maximum degree of uncertainty (Hartley's measure);

b) from the statistical analysis of the image palette we find the probability of pixels with the colour c_j in the image and by the formula (2) we calculate the real informational uncertainty H of the colour distribution in the image;

c) expediency of transformations is determined by the redundancy value of the output information D estimated by the formula (3);

d) if such decision is made, we form the matrix of mutual probabilities;

e) we calculate the value of the mutual entropy $H\,(j,\,i)$ by the formula (6), the mean entropy $H_{av}\,(j,\,i)$ by the formula (4) and the conditional entropy $H\,(j \mid i)$ by the formula (5) or (7);

f) we analyze the relationship (8) and make the decision on the expediency of the image convolution in order to reduce the redundancy of information provided in it by replacing the operations of recording the information about the colour of some pixel by calculations or combining the portion of pixels under the same colour attribute. That is, the specific predicted values of the sequenced pixels colours depend on the colour of the main one and the values obtained in the previous stages of the presented algorithm.

For example:

a) if the value of the p_{ii} element on the main diagonal of the matrix P exceeds the sum of the non-diagonal elements p_{ij} of the i row, then each pixel that stands after c_i, is automatically assigned color c_i;

b) if besides condition (a) the inequality (7) is true, then two options can be chosen:

- for each pixel after c_i, the colour closest to c_i in the color palette of this image is automatically assigned, and c_j is removed from the palette;

- the pixels following the pixels of c_i color, are assigned c_k in the whole the image, provided that $p_{ik} > p_{il}$, $l = 1,\ldots,m$.

As a result, the data amount needed for image recording can be reduced while storing its characteristic features important for the further execution of identification operations.

These rules can be changed by the user in the software, taking into account the nature of the processed images.

For example, for the image in Fig. 3 a the matrix of probabilities P is as follows:

$$P = \begin{pmatrix} 0.7732 & 0.01761 \\ 0.0176 & 0.1916 \end{pmatrix},$$

whereas for a similar but noisy image in Fig. 1 a we get $P\,(91 \times 91)$.

The output statistical characteristics of these images are given in Tab. 1.

Table 1

Statistical characteristics of images in Fig. 1 a and 3 a

Images	In Fig. 3 a	In Fig. 1 a
Pixel dimensions	32 × 32	32 × 32
Number of colours in palette	2	91
H_{max}	1024	6664
H	757	6077
Redundancy D of the represented data	0,26	0,09
H_{av} for pixel pair	486	4890
$H(j \mid i)$	214	3703

As it follows from the estimation of maximum uncertainty, in both cases there is some redundancy while reserving the maximum amount of data for reproducing the images under consideration. Moreover, the inequalities $H_{av} < H$ and $H(j \mid i) < H_{av}(j, i)$ are true. This means that there is no need to store information about the colours of the certain portion of the pixels completely. Without the loss of the main content of the image, it can be partially approximated to the values of neighboring pixels. So the sample of the image convolution in horizontal and vertical directions based on the principle that the colour of the base pixel is assigned to the adjacent right, lower and diagonal pixels is shown in Fig. 3. Changes in the main parameters for the estimation of the information redundancy are given in Tab. 2.

Table 2

Changes of the static characteristics of the image during the folding process

Images	Fig. 3 a	Fig. 3 b	Fig. 3 c	Fig. 3 d
Pixel dimensions	32×32	16×16	8×8	4×4
H_{max}	1024	256	64	16
H	757,3	150,0	48,5	5,4
Redundancy of the represented data	0,28	0,41	0,24	0,66
H_{av}	563,5	113,8	40,7	5,6
$H(j \mid i)$	213,8	77,3	32,6	5,4

As you can see provided that $H_{av} < H$, the characteristic features of the image, important for its identification, are stored while folding (Figures 3 a, 3 b, 3 c), otherwise they are lost (Fig. 3 c). And we see that in the case 3 a the value of the conditional entropy is close to the mean entropy value. That is, the pixel colouring strategy depends on the relationship between $H(j \mid i)$ i H_{av} and the nature of the image itself.

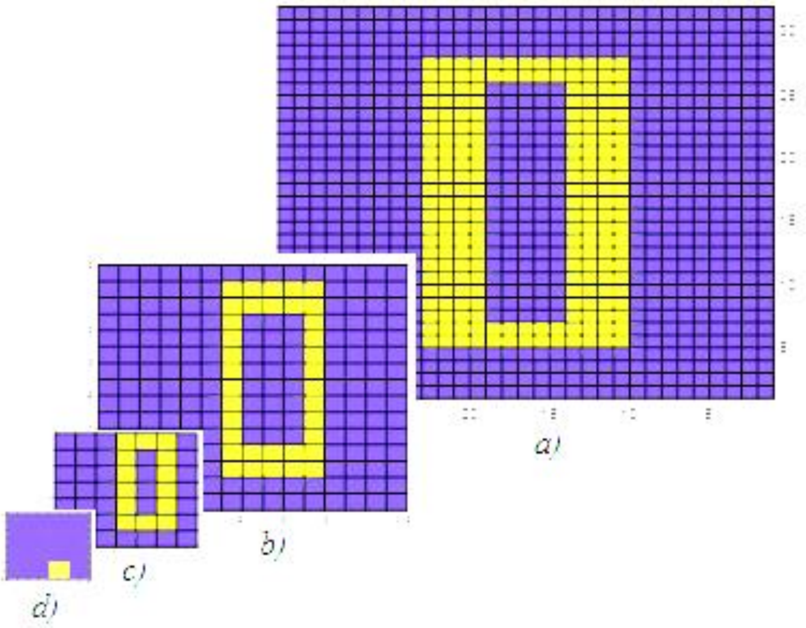

Figure 3. Stages of the image foldover

A similar approach can also be applied to the approximate representation of the sequence of video frames.

The software developed for statistical analysis of video information during its processing allows us to make an effective decision concerning the possibility of the images compression while saving their characteristic features.

Conclusions. The investigation shows how statistical characteristics of the digital image data array, such as estimation of uncertainty and redundancy, can be used while choosing the effective data processing strategy in the multimedia system. Appropriate software for statistical processing of digital images is developed. Examples of its application are considered.

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УДК 004.042

ВИБІР СТРАТЕГІЇ ЕФЕКТИВНОГО ОПРАЦЮВАННЯ ВІДЕОДАНИХ НА ОСНОВІ АНАЛІЗУ СТАТИСТИЧНИХ ХАРАКТЕРИСТИК ЦИФРОВИХ ЗОБРАЖЕНЬ

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Резюме. *Запропоновано методику оцінювання надлишковості відеоданих у сиситемі розпізнавання зображень у реальному часі. Розглянуто способи для зменшення об’єму вхідн даних під час опрацювання цифрових зображень. Запропоновано ефективний підхід для вирішення проблем розпізнавання при аналізуванні динамічної відеоінформації або для фіксування фону, коли частина даних про кольори пікселів цифрового зображення переходить від кадру до кадру без змін. Розглянуто стратегію перетворення зображення під час його опрацювання з метою зменшення об’єму даних, яка залежить від інформаційної надлишковості вхідних даних. Запропоновано алгоритм опрацювання оцифрованого зображення, що керується оцінками максимальнгоо ступеня невизначеності (міра Хартлі) та реальної ентропії цифрового масиву, що відображає кольори пікселів зображення. Реальна інформаційна невизначеність H розподілу кольорів на зображенні обчислюється шляхом статистичного аналізу палітри зображення – обчислення ймовірності пікселів з відповідним кольором у заданому зображенні. Проаналізовано доцільність згортання зображення з метою зменшення надлишковості представлених даних шляхом заміни операції запам’ятовування інформації про кольори частини пікселів розрахунковими операціями або об’єднанням частини пікселів під одним колірним атрибутом. У такому випадку без втрати основного змісту зображення кольори частини пікселів можна частково апроксимувати відповідно до колірних атрибутів сусідніх пікселів. Розглянуто підхід, мотивований оцінками статистичних характеристик цифрових зображень. Висновки опираються на співвідношення між статистичними характеристиками аналізованого зображення, такі, як максимальна, умовна, відносна й середня ентропії масиву даних. Роглянуто зразок згортки зображення в горизонтальному та вертикальному напрямках за принципом, коли колір базового пікселя присвоюється сусіднім правому, нижньому та діагональному пікселям. Наведено зміни базових статистичних параметрів для оцінювання надлишковості інформації. Розгянуто методи, які дозволяють не зберігати повністю інформацію про кольори певної частини пікселів.*

Ключові слова: *розпізнавання образів, надлишковість цифрових зображень, максимальна невизначеність масивів стохастичних даних, умовна ентропія масиву даних.*

Отримано 29.08.2018