Adaptive Optimization of Monochrome Raster Images Tone Approximation

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***Abstract*— One of the main factors that affects on the quality of tone approximation is a proper definition of approximation palette's (AP) structure. The structure represent tones that the AP contains. Thus, there is appear the optimization problem that consists in correct selection of AP for an image. With the purpose to solve the problem, a hybrid algorithm is used. The developed algorithm combine heuristic and deterministic searching approaches in such a way to guarantee at least suboptimal tone approximation. Also the algorithm make possible to realize two-parametric optimization of the tone approximation procedure. The current research is devoted to developing and implementing an adaptive system of changing the number of searching iteration of heuristic stage. The evolutionarily-genetic algorithm is used as a heuristic stage in the developed hybrid algorithm. Statistical investigation allowed to define a criterion of iteration's significance during the search, which allows to approximately estimating the nearness of result to extreme zone. A condition of switching heuristic stage to deterministic one devolved based on the criterion of iteration's significance. The condition allows decreasing the total computational time of the hybrid algorithm. In fact, it is also can considered as optimization of the hybrid algorithm computational time, because the deterministic stage guarantee the extreme result. The experimental investigation confirm the effectiveness of developed adaptive scheme of the hybrid algorithm stages switching compared to fixed strategy.**

Keywords*— tone approximation, images processing; optimization; evolutionarily-genetic algorithm; the extreme conditio; hybrid algorithm

I. Introduction

The size of brightness palette that produce a monochrome multitone image is one of the key parameters that affects on visual quality of the image. Commonly the parameter is called «color depth», but according to the authors opinion the palette's size is more straight term. The modern computational devices allows to process and produce images that represents by 24-bit palette's size, which means operating more than 16 mil colors. However, monochrome images and their tone approximation (reduction of the palette's size) is still demanded in many technical fields. Reduction of the palette's size directly leads to decreasing the image file's size and their visual quality. The optimization of the procedure could allow to minimize the visual quality losses. Besides of effective information compression, the procedure may be useful for simplifying the noises filtration, pattern recognition etc. Reduction of the palette's size make the borders between image objects more obvious, because of significant brightness changing. Such a result could used by described kinds of processing. The current research investigates the process of monochrome multitone images (MMI) tone approximation. The standard palette of MMI contains and operates 256 tones of grey color, where the tone «0» is a black color and «255» is a white color. The consideration of MMI can give more fundamental results on image's tone approximation in generally, because of clear and comprehensible structure of MMI.

II. Problem Formulation

With the purpose to provide optimization of tone approximation procedure it is necessary to develop and investigate modified algorithm for considered problem that guarantee the optimal or suboptimal result, which is satisfied the extreme condition according to approximation quality criterion.

III. Hybrid Algorithm of Optimization the Procedure of Tone Approximation

III.1 Tone approximation of MMI and possibilities of optimization. Above was already described that the task of tone approximation consists in reduction of image's original palette (OP)

$$P^o = (t_1^o, t_2^o, \cdots t_i^o, \cdots, t_{S^o}^o) \tag{1}$$

within initial size of image in pixels. Here in (1) S^o – size of OP, t_i^o – tone of OP.

The standard palette of MMI defined by array of natural numbers that encodes the brightness:

$$P_{256}^o = (0, 1, 2, ..., 255)\,. \tag{2}$$

Reduction of palette realized by replacement of pixel's tones from original MMI (OMMI), which operates values of OP, to tones from approximating palette (AP):

$$P_0^a = (t_{1_0}^a, t_{2_0}^a, \dots t_{j_0}^a, \dots t_{S_0^a}^a) \tag{3}$$

where $S_0^a = S^a$ – size of AP, $t_{j_0}^a$ – tone of AP, the index «0» is mark of some neighborhood's center.

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When the AP is already defined the procedure of pixels replacement produced according to rule of changing some tone t_i^o on t_j^a. It is obvious, that the best result of the approximation will obtain, when average tones deviation between all pixels of approximated (AMMI) and OMMI will minimized, which regulated by AP optimization.

The size of palette is the only difference between structure of AP (3) and OP (1), which means that the same encode brightness are used by AP $0 \le t_j^a \le 255$. For example, the AP with size $S_0^a = 5$ could represents by following structure:

$$P_0^5 = (4, 33, 88, 120, 205). \quad (4)$$

The obvious characteristic of any palette is uniqueness of every palette's tone: $\forall i \ne j \to t_i \ne t_j$, and obvious condition of the approximation is replacement the same tone from OP only with the same tone from AP within whole image. Therefore, quality of the approximation provides by optimization of AP, which is search-optimization problem.

Because of OMMI being is raster digital image, it can be represented as an matrix:

$$P[i,k,l] = \begin{bmatrix} \ddots & \vdots & \iddots \\ \cdots & \left(t_i^o\right)_{kl} & \cdots \\ \iddots & \vdots & \ddots \end{bmatrix}, \quad (5)$$

where k – the number of row, l – the number of column; i –the index of tone t_i^o in OP. Mathematical model (MM) of AMMI also is represented by (5), where the matrix's elements are t_j^a. Such a form of image's MM make possible to organize per element calculation of tones deviation between OMMI and AMMI:

$$Q = \overline{\Delta t\left(P_0^a\right)} = \frac{1}{N} \cdot \sum_{k=1}^{n} \left(\sum_{l=1}^{m} \left| \left(t_{j0}^a\right)_{kl} - \left(t_{i0}^o\right)_{kl} \right| \right). \quad (6)$$

Here n – the number of rows, m – the number of columns, $N = n \cdot m$ – the total number of pixels. The research [1] showed that it is more appropriate to use module of deviation, rather than square deviation.

III.2 Algorithm of optimization the procedure of tone approximation. For solving the problem of AMMI optimization the modified evolutionarily-genetic algorithm (MEGA) is developed, which showed high effectiveness. Besides the traditional genetic and evolutionary mechanism (selection, crossing over, mutation) in MEGA applied special deterministic algorithm that based on image's brightness diagram calculate initial structure of AP, which allow to decrease the area of searching [2, 3].

However, MEGA is a heuristic method, which make difficult to guarantee suboptimal result, for example, local extreme. Due the fact, an additional algorithm is developed for estimating and searching the extreme result. The developed algorithm consists in forming of ε-neighborhood of AP's vector, which is combinatorial set of any S^a elements of type (3) – P_ε^a, which differ from P_0^a not more than on 1. Therefore,

$$\forall t_{j_\varepsilon}^a = t_{j_0}^a + \varepsilon, \varepsilon \in \{-1, 0, 1\} \to t_{j_\varepsilon}^a \in P_\varepsilon^a. \quad (7)$$

The whole set represent in Table I, where the middle row is coordinates of AP's vector that is neighborhood's center.

TABLE I. SINGLE ε - NEIGHBORHOOD OF INVESTIGATED AP

	$t_{1_0}^a$ -1	$t_{2_0}^a$ -1	$t_{3_0}^a$ -1	$\cdots$	$t_{j_0}^a$ -1	$\cdots$	$t_{S_0^a}^a$ -1
$t_{j_\varepsilon}^a =$	$t_{1_0}^a$	$t_{2_0}^a$	$t_{3_0}^a$	$\cdots$	$t_{j_0}^a$	$\cdots$	$t_{S_0^a}^a$
	$t_{1_0}^a$ +1	$t_{2_0}^a$ +1	$t_{3_0}^a$ +1	$\cdots$	$t_{j_0}^a$ +1	$\cdots$	$t_{S_0^a}^a$ +1

The algorithm of any AP P_0^a checking on extreme condition consists in investigation of all her ε - neighborhood $P_\varepsilon^a \subset P^a$ according to criterion of optimization (6) and condition

$$\overline{\Delta t\left(P_0^a\right)} \le \overline{\Delta t\left(P_0^{a\varepsilon}\right)}. \quad (8)$$

If the condition (8) is satisfied, than P_0^a is, at least, a local extreme of tone approximation possible quality. Otherwise, the best AP in neighborhood $P_0^{a_m} = \min\left(P_0^{a_\varepsilon}\right)$ considers as a possible extreme and the procedure of checking repeated until the nearest extreme to initial AP is found. The extreme found by the algorithm could be either global or local. The described algorithm of nearest extreme searching (ANES) is deterministic and NP-hard, which make him applicable only for small S^a. The total number of ε-neighborhood elements of P_0^a for 3 possible values for each AP tone can calculated by enumerating of S^a arrangements with repetition:

$$A_3^{S^a} = 3^{S^a}. \quad (9)$$

It is obvious that the time of P_0^a ε-neighborhood full analysis depend on AP's size and ANES can be effective only when investigated AP is near to extreme zone. For this reason, a decision to develop hybrid algorithm was made, which will use MEGA for decrease the searching area and ANES to guarantee suboptimization.

III.3 The structure and settings of hybrid algorithm of tone approximation optimization. The pilot model of developed hybrid optimization model (HOM) of MMI approximation results showed possibilities to increase quality of tone approximation and computational speed of the problem solving as well [4, 5, 6]. Besides, the algorithm allow to provide bi-optimization of tone approximation procedure according described criterions. Bi-optimization provided due the ANES that guarantee suboptimization, which allow excluding accuracy of tone approximation and considering the total time of hybrid algorithm as the only criterion.

The hybrid model consists in sequential searching of AP structure. The first stage is heuristic approach and the second stage is deterministic one. The reliability level of heuristic stage is not high, but compared to ANES, MEGA need much less computational time. This is allow to use MEGA as a tool for decreasing a searching area. The optimization of MEGA parameters provides increasing the effectiveness of that process. One of the most important settings of hybrid algorithm that affect on algorithm's total time is condition of switching the heuristic stage on deterministic one. If MEGA does not reach an extreme zone close enough, the total time of hybrid algorithm sharply rise due to high computational costs of deterministic stage. The excess steps of MEGA increase the total time too, but much less.

The condition of the switch for HOM investigated and fixed on 20 iterations of MEGA. The experimental investigation on wide set of MMIs showed that this condition can considers as suboptimal. Performed investigation on some OMMIs with size 430 on 240 pixels showed that total time of the algorithm takes 90 seconds under selected condition of switch. During the investigation opened potential possibility to decrease the total time by developing an adaptive algorithm of changing iterations of search in real time. The paper considers results of developing and experimental investigation of managing strategy of MEGA's iterations number that minimizing total time of the HOM. For the purpose designed three-parametric model of adaptive managing of MEGA's iterations number.

For adaptation system three setting parameters are used: number of guaranteed iterations g, number of additional iterations z, and e – constant of effective decreasing of criterion ΔQ during iteration. The scheme of the adaptation (r – index of current searching iteration) represents by following steps:

1. $r < g$ – repeat a search iterations of MEGA;
2. $r = g$ – calculated $\Delta Q_0 = \overline{\Delta t\left(P_0^a\right)_{g-1}} = \overline{\Delta t\left(P_0^a\right)_g}$;
3. $g = g + z$ – switch to additional search iterations;
4. $r < g$ – check the condition of ΔQ improvment

$$\overline{\Delta t\left(P_0^a\right)_{g-1}} - \overline{\Delta t\left(P_0^a\right)_g} < e ; \qquad (9)$$

1. if (9) is not satisfied – back to step 3;
2. if (9) is satisfied – switching to ANES stage.

Adding the parameter g is based on the fact that algorithm MEGA needs some minimal number of searching iterations for reaching to extreme zone. With rise of g also increase the probability of reaching extreme zone and searching time. The MEGA is heuristic algorithm, which negatively affects on reliability factor. The parameter z in this case will help decrease a risk of «looping», because additional iterations give a chance to overcome the zones of local extreme. For finding the appropriate value of criterion e there are performed investigation of images suboptimal approximation. Analysis of ΔQ_a increments for each images allowed to choose e <=0,0001.

For investigation the adaptation process of MEGA by changing the number of searching iterations performed two-factorial experiment with following parameters: z =3, 4 and 5; g =12, 14 и 16 (where 4 and 14 – coordinates of "zero point"). As objects of tone approximation selected exactly the same 6 images that used for suboptimization of fixed number of MEGA iterations. Obviously, it will allow to compare both approaches. All images will processed by hybrid algorithm for each pair of adaptive system parameters. The results of performed experiment showed in table II. The column 1 represent the results of non-adaptive approach with 20 fixed iterations, the columns 2-10 showed the results of performed experiment. In rows «Avg. (average)» and «SD (standard deviation)» are shown the average computational time of HMO among all tested images. All settings, except 4 (90.1 sec.), allow to decrease the average total time compared to 1 (89.3 sec.). The best setting (3) decrease the average total time only on ~6% (83.9 sec.).

TABLE II. THE RESULTS OF PERFORMED EXPERIMENT

№	1	2	3	4	5	6	7	8	9	10
z	Нет		3			4			5	
g	20	12	14	16	12	14	16	12	14	16
Avg.	89,3	86,9	83,9	90,1	84,3	86,3	85,2	85,9	86,8	87,1
SD	15,4	11,7	10,9	10,1	7,7	10,1	11,4	9,6	11,1	9,2

However, the SD analysis (for 1 – 15.4 sec., for 5 – 7.7. sec.) showed his significant reduction. It means that adaptive approach to each image decrease the probability of non-reach to extreme. Thus, the adaptive system allow to improvement the reliability of HOM's output results.

This conclusion is clearly confirmed by diagram on Fig. 1 that illustrated below. The diagram columns presents the average total time of searching (the top of gray) and his range (from the bottom of gray to top of light gray). The confidence probability for shown ranges is ~70%. It is easy to notice that maximum of possible time of HOM is significantly decrease.

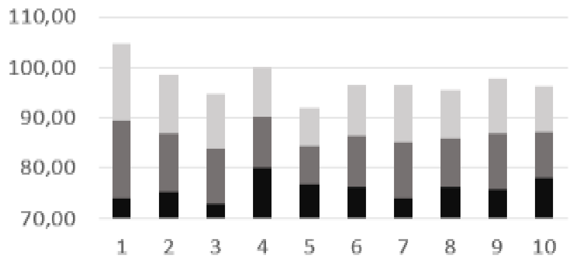

Fig. 1. Dependency of the hybrid algorithm time intervals from MEGA's adaptive system settings

Thus, as quasi-optimal setting of adaptive system for HMO can be considered $z = 4$ and $g = 12$, which gives minimum of possible time interval and second best average time for the algorithm. However, significantly uncertainty of results makes reasonable to continue investigations of defining the best values for the parameters and finding the ways to modify the adaptive system.

In addition, it is necessary to notice that for potential increasing of developed adaptive system effectiveness also need to investigate different values of e parameter.

IV. Заключение

The main results of performed investigation include the following:

1. proposed as HOM the hybrid algorithm of monochrome images tone approximation, which unite heuristic modified evolutionarily-genetic algorithm (MEGA) of initial search for optimal quality area, and deterministic algorithm of nearest extreme searching (ANES) for this area, showed high effectiveness and obvious perspectives;
2. in the paper showed that using the ANES in HOM guarantee suboptimal or even optimal result according to approximation quality, and the MEGA's settings significantly affects on total time of HMO, which allow to choose the time as only criterion for HMO optimization;
3. the experimental investigation of integrated adaptive system of managing the search iterations in MEGA allowed to find suboptimal settings that provide decreasing (on ~6.3%) of processing time satisfying the condition of extreme result, and also reduce the maximal level of confident maximum time of searching;
4. it is reasonable to continue investigations in direction of modifying and suboptimizing of adaptive system.

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