Improving the JPEG-LS compression of images with locally sparse histograms

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Abstract **– In this paper, we propose a preprocessing technique that is capable of improving the compression of images that have locally sparse intensity histograms. In this case, (global) off-line histogram packing may be unsuitable. However, by reducing the size of the symbol-set used by the packing procedure, we are able to attain globally better results, being some of them quite dramatic.**

I. INTRODUCTION

Off-line histogram packing is a known method capable of producing improvements if applied prior to the lossless compression of images having sparse histograms. Basically, off-line histogram packing relies on the construction of an one-to-one order-preserving mapping from the image intensity values into a contiguous subset of the integers. For constructing this mapping we need to know, *a priori*, which intensity values are present in the image. If that is unknown, which is the most often case, then we need to perform a pass through the image in order to find out those intensity values. In the latter case, the complete encoding process, i.e., histogram packing and lossless image coding, cannot be performed on-line. On-line strategies have been recently proposed, some of them designed specifically for a particular encoding algorithm [1, 2], some others designed to act as a preprocessing stage detached from the particular encoding algorithm that is used [3].

Generally, the off-line histogram packing method is very effective in images characterized by having sparse histograms. This can be verified in the examples given in Table I, where compression ratios obtained before and after off-line histogram packing are presented. As can be observed, the compression improvement after off-line histogram packing is very significant for images having sparse histograms, i.e., the images in the first group and some of the images in the third group.

However, generally, image data are not stationary. Therefore, a global histogram may not express correctly how intensities are used in different parts of the image. In the remainder of this paper we present an approach that aims at exploring non-stationary characteristics of the intensity histogram.

II. THE PACKING ALGORITHM

Let us denote by $\mathcal{I}$ the set of all different intensity values used by a given image, and by $S \in \mathbb{N}$ some predefined value. During the processing of sample x^t,[1] which generates a transformed sample y^t at time instant t, we assume that a previously constructed subset of $\mathcal{I}$, $\mathcal{I}_n^t$, is available:

$$\mathcal{I}_n^t = \{I_0, I_1, \ldots, I_{n-1}\}, \quad n \leq S.$$

Moreover, we assume without loss of generality that $I_i < I_j, \forall_{i<j}$, and that the following one-to-one, order-preserving mapping in $\mathbb{N}_0$ is also available:

$$h^t = (I_0 \mapsto 0, I_1 \mapsto 1, \ldots, I_{n-1} \mapsto n-1).$$

Sample x^t is processed as follows. If $x^t \in \mathcal{I}_n^t$, then $y^t = h^t(x^t)$. However, if $x^t \notin \mathcal{I}_n^t$, then $y^t = n$, which is the first element of $\mathbb{N}_0$ that does not belong to $h^t(\mathcal{I}_n^t)$. In this case, the intensity value $\tilde{I} = x^t$ is stored into a file, which is used for later recovery of the original image intensity values. We call this file the "recovery file".

The occurrence of an intensity not belonging to $\mathcal{I}_n^t$ also implies the rearrangement of the mapping, which depends on whether $n = S$ or not. If $n < S$, and assuming that $I_i < \tilde{I} < I_{i+1}$, then the new mapping is:

$$h^{t+1} = (\ldots, I_i \mapsto i, \tilde{I} \mapsto i+1, I_{i+1} \mapsto i+2, \ldots, I_{n-1} \mapsto n).$$

As can be seen, $\tilde{I}$ is inserted in the mapping in such a way that the one-to-one, order-preserving property is maintained. On the other hand, if $n = S$, in addition to the inclusion of $\tilde{I}$ in the mapping, as described above, it is also required the deletion of one of the members of $\mathcal{I}_n^t$ (i.e., the cardinality of the set is kept equal to S). Also in this case, the mapping has to be rearranged in order to obey to the one-to-one, order-preserving property.

Decoding is performed using a similar strategy as encoding. When decoding sample y^t, if $y^t < S$, then $x^t = (h^t)^{-1}(y^t)$. [2] Otherwise, an intensity value, $\tilde{I}$, is fetched from the recovery file and $x^t = \tilde{I}$. The mapping is always reorganized following the same procedures as those performed by the encoder.

III. EXPERIMENTAL RESULTS AND CONCLUSIONS

Table I presents compression results using the most recent ISO/IEC standard and ITU recommendation for the lossless compression of continuous-tone images: JPEG-LS [4, 5] (we used the implementation provided by the Signal Processing & Multimedia Group at the University of

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[1] We assume that the image samples have been transformed into a sample sequence, x^t, using some image scanning strategy. In this work we used a raster-scanning approach.

[2] Notation $(h^t)^{-1}$ indicates a mapping that is the inverse of h^t.

Image	Intensities	Normal		Off-line packing			Proposed method			
		Size	bps	Size	bps	%	Size	bps	%	S
benjerry	48	6,707	1.919	4,881	1.396	27.2	4,784	1.368	28.7	26
books	7	39,859	5.601	13,396	1.882	66.4	11,657	1.638	70.8	5
cmpndd	133	71,469	1.454	62,431	1.270	12.6	61,733	1.255	13.6	108
cmpndn	132	58,639	1.193	51,619	1.050	12.0	51,298	1.043	12.5	106
gate	69	27,656	3.632	20,718	2.721	25.1	21,692	2.848	21.6	64
music	8	4,534	2.943	1,747	1.134	61.5	1,894	1.229	58.2	8
netscape	27	21,249	2.777	13,191	1.724	37.9	12,957	1.693	39.0	26
sea_dusk	43	4,061	0.206	3,479	0.176	14.3	1,446	0.073	64.4	3
sunset	138	83,552	2.175	75,412	1.963	9.7	74,761	1.946	10.5	136
winaw	10	48,189	1.309	20,102	0.546	58.3	19,286	0.524	60.0	7
yahoo	156	8,822	2.600	8,401	2.476	4.8	7,382	2.175	16.3	3
Total	—	**374,737**	—	**275,377**	—	**26.5**	**268,890**	—	**28.2**	—
aerial2	256	2,772,925	5.288	2,773,183	5.289	0.0	2,250,493	4.292	18.8	117
bike	220	2,854,695	4.355	2,600,571	3.968	8.9	2,604,249	3.973	8.8	220
bikeh	220	144,412	5.516	134,535	5.139	6.8	136,167	5.201	5.7	220
cafe	220	3,336,249	5.090	3,238,178	4.941	2.9	3,238,527	4.941	2.9	220
goldhill	220	154,391	4.711	154,637	4.719	-0.2	155,609	4.748	-0.8	204
lena	215	139,106	4.245	139,340	4.252	-0.2	140,146	4.276	-0.7	209
woman	220	220,671	5.387	212,511	5.188	3.7	212,998	5.200	3.5	220
Total	—	**9,622,449**	—	**9,252,955**	—	**3.8**	**8,738,189**	—	**9.2**	—
france	249	58,792	1.411	58,602	1.406	0.3	19,812	0.475	66.3	3
frog	102	233,831	6.048	200,089	5.175	14.4	176,525	4.566	24.5	11
library	221	104,140	5.100	102,217	5.006	1.8	100,139	4.904	3.8	174
mountain	110	246,604	6.421	201,417	5.245	18.3	198,728	5.175	19.4	95
washsat	35	135,309	4.129	65,734	2.006	51.4	65,767	2.007	51.4	35
Total	—	**778,676**	—	**628,059**	—	**19.3**	**560,971**	—	**28.0**	—

Table I

COMPRESSION RESULTS (NUMBER OF BYTES AND BITS/SAMPLE) OBTAINED WITH JPEG-LS APPLIED DIRECTLY TO THE IMAGES ("NORMAL"), APPLIED AFTER OFF-LINE PACKING ("OFF-LINE PACKING"), AND APPLIED AFTER USING THE METHOD PROPOSED IN THIS PAPER ("PROPOSED METHOD"). PERCENTAGES REPRESENT COMPRESSION GAINS IN RELATION TO THE "NORMAL" VALUES.

British Columbia (SPMG / JPEG-LS V.2.2 codec, `ftp://spmg.ece.ubc.ca/pub/jpeg-ls/ver-2.2/`).

To assess the efficiency of the proposed technique we used three sets of images. Two of them were those used by Yoo *et al.* to test the efficiency of EIDAC, an embedded image-domain adaptive compression technique, specialized in the compression of "simple images" (expression used by some authors to designate images with sparse histograms) [6]. The first set (corresponding to the first group of images in Table I) is a gray-scale-converted version of a set used by Ausbeck in its PWC coder [7].

The second set (second group in Table I) comprises several natural images and has the objective of testing the robustness of the method in images that are not "simple" (this set was also used in [6]). The third set (last group of images in Table I) is composed of five images taken from the BragZone archive. This set was recently used to illustrate the poor performance of JPEG-LS in compressing this type of images [8].

From the observation of the "Total" rows in Table I, we can immediately conclude that the proposed method provides globally better results than the normal off-line packing. Looking at individual images, we can notice some dramatic improvements. That is the case of image "france", which gets a compression improvement of 66%. The compression of image "sea_dusk" improves 58%. Also, a considerable 19% improvement can be noticed in the compression of image "aerial2". This percentages represent improvements over the normal off-line packing method. Other less dramatic but also important improvements can be observed in other images.

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