Description of a new set of medical and natural continuous tone grayscale test images

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1. General set description

The set described here was prepared to evaluate the performance of lossless image compression algorithms for medical and natural continuous tone grayscale images. The set contains natural continuous tone grayscale images of various bit depths (up to 16 bits), various sizes (up to about 4 millions of pixels) and medical images of various modalities (CR, CT, MR, and US). In the set, image groups were defined, to permit performance analysis based on average results for the whole group, rather than on results for single images. The biggest group, *normal*, is for evaluating algorithms' performance in a typical case, i.e., average results of compressing images from the *normal* group may serve as a measure of algorithms' average performance for continuous tone grayscale images. A collection of smaller groups permits to analyze or compare results with respect to images' bit depths, sizes, or medical image modality. The set contains also non-typical images, which do not belong to the *normal* group. To analyze the algorithms' performance on noisy data special images with added noise were prepared. To estimate the best-case and the worst-case performance of algorithms, easily compressible and incompressible pseudo-images were also generated. The set is publicly available and may be downloaded from http://sun.iinf.polsl.gliwice.pl/~rstaros/mednat/index.htm.

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2. Image groups

2.1. Natural images

Natural images are continuous tone images acquired from scenes available for human eye (photographic images). The group of *natural* images was constructed as follows. Four images were acquired from a 36mm high quality diapositive film (Fuji Provia/Velvia) using Minolta Dimage 5400 scanner. In order to minimize the noise, the acquisition was first done at device's maximum depth of 16 bits, optical resolution 5400dpi, and using multiple sampling of each pixel. One image ("flower") was softened by setting scanner focus too close. For all images, but one ("branches"), we used the scanner's optical mechanism of reducing visibility of the film grain ("grain dissolver"). Then images' resolution was reduced 3 times. These images formed a group of 16-bit big images, and then were subject to further resolution reduction (3 and 9 times) and to bit depth reduction (to 12 and to 8 bits). The set contains following groups of natural images:

- *natural*—main group of natural images, 36 natural images of various sizes and bit depths,
- *big*—12 natural images of various bit depths and size approximately 4000000 pixels,
- *medium*—12 natural images of various bit depths and size approximately 440000 pixels,
- *small*—12 natural images of various bit depths and size approximately 49000 pixels,
- *16bpp*—12 natural images of various sizes and 16-bit depth,
- *12bpp*—12 natural images of various sizes and 12-bit depth,
- *8bpp*—12 natural images of various sizes and 8-bit depth.


"branches"


"flower"


"kid"


"town"

Sample *natural* images.

2.2. Medical images

Groups of medical images were composed of CR, CT, MR, and US images of various anatomical regions, acquired from devices of several vendors. Note, that in case of medical CR, CT, and MR images, the nominal bit depth may be misleading. Actual number of intensity levels of these images may be smaller than implied by the bit depth by an order of magnitude or even more—see the Table 1 for details. Set contains following groups of medical images:

- *medical*—main group of natural images, 48 medical CR, CT, MR, and US images,
- *cr*—12 medical CR images, nominal depth: 10 to 16 bits, average size approximately 3500000 pixels,
- *ct*—12 medical CT images, nominal depth: 12 to 16 bits, average size approximately 260000 pixels,
- *mr*—12 medical MR images, nominal depth of 16 bits, average size approximately 200000 pixels,
- *us*—12 medical US images, 8-bit depth, average size approximately 300000 pixels.

2.3. The normal group

The *normal* group is a main group of the set; it contains all 84 images from groups *natural* and *medical*. The *normal* group is for evaluating algorithms' performance in a typical case, i.e., average results of compressing images from the *normal* group may serve as a measure of algorithm's average performance for continuous tone grayscale images.

2.4. Non-typical images

Following groups of non-typical images are contained in the set:

- *noise*—9 images with added noise, created using "branches" image of various bit depths (8, 12, and 16 bits) and medium size (approximately 440000 pixels). Noise was added using: $v_1 = v_0 (1 - a) + r\,a$, where v_0 denotes original pixel intensity, v_1—intensity after adding noise, r—random value of uniform distribution, and a is the amount of noise. We prepared images using $a = 0.1$, 0.2, and 0.5,
- *empty*—3 pseudo-images, intensity of all pixels equals 0, nominal depth of 8, 12, and 16 bits, size approximately 440000 pixels,
- *random*—3 pseudo-images, random intensities of pixels (uniform distribution), bit depth of 8, 12, and 16 bits, size approximately 440000 pixels.

The *random* pseudo-images may be used to evaluate the worst-case performance of an image compression algorithm, however modern image compression algorithms are based on sophisticated assumptions as to characteristics of data they process. For a specific image compression algorithm we could prepare data even harder to compress, i.e., pseudo-image of characteristics opposite to what is expected in the compression algorithm.

3. Image details

The Table 1 contains basic characteristics of all the images. In this table we also report the actual number of pixel intensity levels (levels) and the memoryless entropy of image data in bits per pixel (H0). Details on origin of the medical images are presented in the Table 2.

Table 1. Image details.

image	width	height	pixels	bpp	levels	H0	groups
im_branches_03_16	2458	1610	3957380	16	62207	15.543	*big, 16bpp, natural, normal*
im_flower_03_16	2458	1610	3957380	16	65191	14.314	*big, 16bpp, natural, normal*
im_kid_03_16	2474	1621	4010354	16	64393	14.919	*big, 16bpp, natural, normal*
im_town_03_16	2464	1610	3967040	16	64528	15.443	*big, 16bpp, natural, normal*
im_branches_09_16	819	536	438984	16	58919	15.445	*medium, 16bpp, natural, normal*
im_flower_09_16	819	536	438984	16	46033	14.206	*medium, 16bpp, natural, normal*
im_kid_09_16	824	540	444960	16	60421	14.867	*medium, 16bpp, natural, normal*
im_town_09_16	821	536	440056	16	57984	15.323	*medium, 16bpp, natural, normal*
im_branches_27_16	273	178	48594	16	29543	14.635	*small, 16bpp, natural, normal*
im_flower_27_16	273	178	48594	16	17840	13.702	*small, 16bpp, natural, normal*
im_kid_27_16	274	180	49320	16	25348	14.210	*small, 16bpp, natural, normal*
im_town_27_16	273	178	48594	16	27965	14.529	*small, 16bpp, natural, normal*
im_branches_03_12	2458	1610	3957380	12	3906	11.554	*big, 12bpp, natural, normal*
im_flower_03_12	2458	1610	3957380	12	4081	10.326	*big, 12bpp, natural, normal*
im_kid_03_12	2474	1621	4010354	12	4076	10.990	*big, 12bpp, natural, normal*
im_town_03_12	2464	1610	3967040	12	4066	11.454	*big, 12bpp, natural, normal*
im_branches_09_12	819	536	438984	12	3870	11.546	*medium, 12bpp, natural, normal*
im_flower_09_12	819	536	438984	12	4077	10.317	*medium, 12bpp, natural, normal*
im_kid_09_12	824	540	444960	12	4037	11.006	*medium, 12bpp, natural, normal*
im_town_09_12	821	536	440056	12	4020	11.430	*medium, 12bpp, natural, normal*
im_branches_27_12	273	178	48594	12	3728	11.482	*small, 12bpp, natural, normal*
im_flower_27_12	273	178	48594	12	3438	10.253	*small, 12bpp, natural, normal*
im_kid_27_12	274	180	49320	12	3918	11.027	*small, 12bpp, natural, normal*
im_town_27_12	273	178	48594	12	3818	11.332	*small, 12bpp, natural, normal*
im_branches_03_08	2458	1610	3957380	8	246	7.555	*big, 8bpp, natural, normal*
im_flower_03_08	2458	1610	3957380	8	256	6.330	*big, 8bpp, natural, normal*
im_kid_03_08	2474	1621	4010354	8	255	7.052	*big, 8bpp, natural, normal*
im_town_03_08	2464	1610	3967040	8	255	7.458	*big, 8bpp, natural, normal*
im_branches_09_08	819	536	438984	8	242	7.553	*medium, 8bpp, natural, normal*
im_flower_09_08	819	536	438984	8	256	6.327	*medium, 8bpp, natural, normal*
im_kid_09_08	824	540	444960	8	255	7.052	*medium, 8bpp, natural, normal*
im_town_09_08	821	536	440056	8	253	7.444	*medium, 8bpp, natural, normal*
im_branches_27_08	273	178	48594	8	241	7.538	*small, 8bpp, natural, normal*
im_flower_27_08	273	178	48594	8	255	6.324	*small, 8bpp, natural, normal*
im_kid_27_08	274	180	49320	8	249	7.095	*small, 8bpp, natural, normal*
im_town_27_08	273	178	48594	8	250	7.404	*small, 8bpp, natural, normal*
cr_17218	2392	1792	4286464	12	2068	9.950	*cr, medical, normal*
cr_17220	2500	2048	5120000	12	3186	9.307	*cr, medical, normal*
cr_17222	1792	2392	4286464	12	2939	9.798	*cr, medical, normal*
cr_4503	1670	2010	3356700	10	256	7.501	*cr, medical, normal*
cr_4507	1760	1760	3097600	10	1024	6.625	*cr, medical, normal*
cr_4509	1760	2140	3766400	10	882	9.301	*cr, medical, normal*
cr_pacem_1	1716	1910	3277560	16	24180	13.808	*cr, medical, normal*
cr_pacem_2	1531	1965	3008415	16	28627	14.254	*cr, medical, normal*
cr_rtg_jb	612	746	456552	16	3280	11.456	*cr, medical, normal*
cr_siem_01_02	1744	2128	3711232	10	913	9.214	*cr, medical, normal*
cr_siem_14_02	1760	2368	4167680	10	638	6.159	*cr, medical, normal*
cr_slim_1	1866	2031	3789846	16	26539	13.973	*cr, medical, normal*

image	width	height	pixels	bpp	levels	H0	groups
ct_135960_001	512	512	262144	16	2442	7.593	*ct, medical, normal*
ct_135960_005	512	512	262144	16	2806	7.680	*ct, medical, normal*
ct_17	512	512	262144	12	1883	7.356	*ct, medical, normal*
ct_27154	512	512	262144	12	1300	5.584	*ct, medical, normal*
ct_29513	340	340	115600	12	2570	7.442	*ct, medical, normal*
ct_29920	512	512	262144	12	1723	7.076	*ct, medical, normal*
ct_3030	512	691	353792	16	778	8.884	*ct, medical, normal*
ct_3071	512	512	262144	16	1696	7.578	*ct, medical, normal*
ct_4006	512	512	262144	16	2100	9.168	*ct, medical, normal*
ct_4087	512	512	262144	16	1731	9.553	*ct, medical, normal*
ct_4165	512	512	262144	16	1735	9.563	*ct, medical, normal*
ct_tk_kl_piers0021	512	512	262144	16	2644	8.274	*ct, medical, normal*
mr_2321	512	512	262144	16	894	8.288	*mr, medical, normal*
mr_2331	512	512	262144	16	893	8.433	*mr, medical, normal*
mr_2337	512	512	262144	16	1047	6.797	*mr, medical, normal*
mr_2371	512	512	262144	16	1415	6.727	*mr, medical, normal*
mr_2412	512	512	262144	16	1300	7.831	*mr, medical, normal*
mr_2807	256	256	65536	16	1858	10.151	*mr, medical, normal*
mr_2882	512	512	262144	16	501	1.696	*mr, medical, normal*
mr_2896	512	512	262144	16	604	6.554	*mr, medical, normal*
mr_6624	256	256	65536	16	795	7.485	*mr, medical, normal*
mr_6706	256	256	65536	16	1088	8.188	*mr, medical, normal*
mr_6774	512	512	262144	16	1799	6.901	*mr, medical, normal*
mr_6837	256	256	65536	16	1055	7.389	*mr, medical, normal*
us_19773	640	480	307200	8	256	3.770	*us, medical, normal*
us_27704	640	480	307200	8	249	4.756	*us, medical, normal*
us_27743	640	480	307200	8	246	4.968	*us, medical, normal*
us_28279	640	480	307200	8	250	3.725	*us, medical, normal*
us_28282	640	480	307200	8	247	5.416	*us, medical, normal*
us_28289	640	480	307200	8	254	3.292	*us, medical, normal*
us_28322	640	480	307200	8	213	4.964	*us, medical, normal*
us_28329	640	480	307200	8	213	5.374	*us, medical, normal*
us_28348	640	480	307200	8	217	4.150	*us, medical, normal*
us_3393	640	476	304640	8	218	5.911	*us, medical, normal*
us_3403	584	484	282656	8	256	4.868	*us, medical, normal*
us_3405	640	476	304640	8	197	3.565	*us, medical, normal*
in_town_09_08_an10	821	536	440056	8	251	7.551	*noise*
in_town_09_08_an20	821	536	440056	8	251	7.598	*noise*
in_town_09_08_an50	821	536	440056	8	253	7.665	*noise*
in_town_09_12_an10	821	536	440056	12	3978	11.541	*noise*
in_town_09_12_an20	821	536	440056	12	3972	11.589	*noise*
in_town_09_12_an50	821	536	440056	12	4000	11.656	*noise*
in_town_09_16_an10	821	536	440056	16	58177	15.438	*noise*
in_town_09_16_an20	821	536	440056	16	59358	15.488	*noise*
in_town_09_16_an50	821	536	440056	16	59633	15.553	*noise*
in_wdrag_09_08	821	536	440056	8	1	0.000	*empty*
in_wdrag_09_12	821	536	440056	12	1	0.000	*empty*
in_wdrag_09_16	821	536	440056	16	1	0.000	*empty*
in_wnoise_09_08	821	536	440056	8	256	8.000	*random*
in_wnoise_09_12	821	536	440056	12	4096	11.994	*random*
in_wnoise_09_16	821	536	440056	16	65460	15.889	*random*

Table 2. Origin of medical images.

image	origin	origin details
cr_17218	***	RSNA96\kodak-7.tar (kodak\KHIS073006030\CR.17218.1.Z)
cr_17220	***	RSNA95\kodak-8.tar (kodak\KHIS073013420\CR.17220.1.Z)
cr_17222	***	RSNA95\kodak-9.tar (kodak\KHIS080105590\CR.17222.1.Z)
cr_4503	***	RSNA96\fuji-32.tar (fuji\FUJI95701\CR.4503.1.Z)
cr_4507	***	RSNA96\fuji-34.tar (fuji\FUJI95706\CR.4507.1.Z)
cr_4509	***	RSNA96\fuji-35.tar (fuji\FUJI95707\CR.4509.1.Z)
cr_pacem_1	**	Thoravision_3.3\pacem-1.dic
cr_pacem_2	**	Thoravision_3.3\pacem-2.dic
cr_rtg_jb	*	
cr_siem_01_02	***	RSNA94\siemens-18.tar (siemens-18\SIEMENS_RXDpat1_img02.Z)
cr_siem_14_02	***	RSNA94\siemens-19.tar (siemens-19\SIEMENS_RXDpat14_img02.Z)
cr_slim_1	**	Thoravision_3.3\slim-1.dic
ct_135960_001	*	
ct_135960_005	*	
ct_17	***	RSNA96\algotec-24.tar (algotec\ALGO00002\CT.17.1.Z)
ct_27154	***	RSNA96\siemens-27.tar (siemens\SMS000018\CT.27154.1.Z)
ct_29513	***	RSNA96\algotec-23.tar (algotec\ALGO00000\CT.29513.1.Z)
ct_29920	***	RSNA96\algotec-24.tar (algotec\ALGO00002\CT.29920.1.Z)
ct_3030	***	RSNA96\ge-17.tar (ge\THU9948\CT.3030.1.Z)
ct_3071	***	RSNA96\ge-17.tar (ge\THU9948\CT.3071.1.Z)
ct_4006	***	RSNA96\picker-3.tar (CT.4006.1.Z)
ct_4087	***	RSNA96\picker-3.tar (CT.4087.1.Z)
ct_4165	***	RSNA96\picker-3.tar (CT.4165.1.Z)
ct_tk_kl_piers0021	*	
mr_2321	***	RSNA96\ge-19.tar (ge\1.2.840.113674.1118.54.200\MR.2321.1.Z)
mr_2331	***	RSNA96\ge-19.tar (ge\1.2.840.113674.1118.54.200\MR.2331.1.Z)
mr_2337	***	RSNA96\ge-19.tar (ge\1.2.840.113674.1118.54.200\MR.2337.1.Z)
mr_2371	***	RSNA96\ge-19.tar (ge\1.2.840.113674.1118.54.200\MR.2371.1.Z)
mr_2412	***	RSNA96\ge-20.tar (ge\1.2.840.113674.1335.106.200\MR.2412.1.Z)
mr_2807	***	RSNA96\ge-21.tar (ge\1.2.840.113674.1140.196.200\MR.2807.1.Z)
mr_2882	***	RSNA96\ge-22.tar (ge\1.2.840.113674.1115.261.200\MR.2882.1.Z)
mr_2896	***	RSNA96\ge-22.tar (ge\1.2.840.113674.1115.261.200\MR.2896.1.Z)
mr_6624	***	RSNA96\picker-4.tar (MR.6624.1.Z)
mr_6706	***	RSNA96\picker-5.tar (MR.6706.1.Z)
mr_6774	***	RSNA96\picker-6.tar (MR.6774.1.Z)
mr_6837	***	RSNA96\picker-6.tar (MR.6837.1.Z)
us_19773	***	RSNA96\toshiba-16.tar (toshiba\TMS061001\US.19773.1.Z)
us_27704	***	RSNA96\acuson-11.tar (acuson\ACN000001\US.27704.1.Z)
us_27743	***	RSNA96\acuson-11.tar (acuson\ACN000001\US.27743.1.Z)
us_28279	***	RSNA96\acuson-11.tar (acuson\ACN000001\US.28279.1.Z)
us_28282	***	RSNA96\acuson-11.tar (acuson\ACN000001\US.28282.1.Z)
us_28289	***	RSNA96\acuson-12.tar (acuson\ACN000004\US.28289.1.Z)
us_28322	***	RSNA96\acuson-13.tar (acuson\ACN000104\US.28322.1.Z)
us_28329	***	RSNA96\acuson-13.tar (acuson\ACN000104\US.28329.1.Z)
us_28348	***	RSNA96\acuson-13.tar (acuson\ACN000104\US.28348.1.Z)
us_3393	***	RSNA96\atl-36.tar (atl\ATL000001\US.3393.1.Z)
us_3403	***	RSNA96\atl-38.tar (atl\ATL000013\US.3403.1.Z)
us_3405	***	RSNA96\atl-39.tar (atl\ATL000015\US.3405.1.Z)

*) images supplied by Prof. Ewa Piętka (Silesian University of Technology)

**) Philips Medical Systems DICOM Reference Medical Images
ftp://ftp-wjq.philips.com/medical/interoperability/out/Medical_Images/

***) publicly available DICOM images of the RSNA conference
ftp://wuerlim.wustl.edu/pub/dicom/images/version3/