An evaluation of lossless compression algorithms for medical infrared images

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***Abstract*— Several popular lossless image compression algorithms were evaluated for the application of compressing medical infrared images. Lossless JPEG, JPEG-LS, JPEG2000, PNG, and CALIC were tested on an image dataset of 380+ thermal images. The results show that JPEG-LS is the algorithm with the best performance, both in terms of compression ratio and compression speed.**

I. INTRODUCTION

Advances in camera technologies and reduced equipment costs have lead to an increased interest in the application of infrared imaging in the medical fields [5]. Medical infrared imaging uses a camera with sensitivities in the (near)infrared to provide a picture of the temperature distribution of the human body or parts thereof. It is a non-invasive, radiation-free technique that is often being used in combination with anatomical investigations based on x-rays and three-dimensional scanning techniques such as CT and MRI and often reveals problems when the anatomy is otherwise normal. It is well known that the radiance from human skin is an exponential function of the surface temperature which in turn is influenced by the level of blood perfusion in the skin. Thermal imaging is hence well suited to pick up changes in blood perfusion which might occur due to inflammation, angiogenesis or other causes. Computerised image processing and pattern recognition techniques have been used in acquiring and evaluating medical thermal images [8], [15] and proved to be important tools for clinical diagnostics.

Medical infrared images are captured and stored in digital form. Obviously, the more images are captured the more attention has to be put on necessary resources such as storage space and bandwidth. For example, the images for one person captured according to [9] which suggests 27 standard views requires, assuming a 12-bit thermal camera with 680×512 resolution, more than 13 megabytes of disk space. The application of compression methods is therefore often a necessary step to reduce these storage requirements. For images there are two kinds of compression methods: lossless compression which preserves all of the original information and lossy compression which sacrifices some of the visual quality to gain in terms of compression rate. While approaches for lossy compression of medical infrared images have been presented [11], [12] clinicians often prefer lossless algorithms to ensure no information is lost. Also, in some countries it is forbidden by law to lossly compress images used for medical diagnosis.

In this paper we evaluate several ”standard” lossless image compression algorithms for compressing medical infrared images. Lossless JPEG [6], JPEG-LS [3], JPEG2000 [4], PNG [18], and CALIC [16], [17] are compared on an image set comprising more than 380 thermal images organised into 20 groups according to [9].

abbreviation	description	no. of images
ABD	abdomen, anterior view	19
BAA	both ankles, anterior view	21
BHD	both hands, dorsal view	16
BKA	both knees, anterior view	18
CA	chest, anterior view	22
DF	dorsal feet	15
FA	face	23
LAD	left arm, dorsal view	15
LB	lower back, dorsal view	17
LLA	lower legs, anterior view	20
LLD	lower legs, dorsal view	19
LRL	right leg, lateral view	19
ND	neck, dorsal view	23
PF	plantar feet	23
TA	thighs, anterior view	20
TBA	total body, anterior view	19
TBD	total body, dorsal view	16
TBR	total body, right view	17
TD	thighs, dorsal view	18
UB	upper body, dorsal view	22
total		**382**

TABLE I

IMAGE GROUPS IN THE DATASET.

The rest of the paper is organised as follows: Section II introduces the image set used for the study while Section III explains the experimental procedure. Section IV briefly describes the image compression algorithms investigated and lists the results which are discussed in Section V. Section VI concludes the paper.

II. IMAGE DATASET

In order to provide a useful comparison of the performance of compression algorithms one requires an image set that reflects the diversity of types of thermal images that are typically captured. We have therefore compiled such a data set which follows the standard views introduced in [9]. There, 27 standard poses are defined which which are designed to capture every view possible necessary for composing an atlas

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based on infrared imaging. Of these 27 views we omitted 7 poses which are very similar to some of the other ones ones due to symmetry reasons (either left/right or anterior/dorsal). Of each of the remaining 20 image groups about 20 images were collected using CTHERM [8]; for details regarding each group please refer to Table I. With a few exceptions all images are of size 680×512, and the image bit depth is 7 bits.

III. Experimental Procedure

Experimental results were obtained on a HP Proliant ML350G3 computer equipped with two Intel Xeon 3.06 GHz (512 kB cache memory) processors and Windows 2003 operating system. Single-threaded applications of algorithms used for comparisons were compiled using Intel C++ 8.1 compiler. To minimise effects of the system load and the input-output subsystem the compressors were run several times. The time of the first run was ignored while the collective time of other runs (executed for at least one second, and at least 5 times) was measured and then averaged. The time measured is hence the sum of time spent by the processor in application code and in kernel functions called by the application, as reported by the operating system after application execution. In case of the CALIC algorithm which is available as a binary executable for UltraSparc processors, the compression speed is estimated based on the relative speed of this implementation measured on another computer system (Sun Fire V440 running Solaris 9, equipped with 1.06GHz UltraSparc IIIi processors). The compression speed is reported in megabytes per second [MB/s], where 1MB = 2^{20} bytes. The compression ratio is defined as O/C where O is the filesize of the original images and C that of the compressed file.

images	**L-JPG**	**JPEG-LS**	**JPEG2000**	**PNG**	**CALIC**
ABD	11.9	17.7	3.8	3.3	4.1
BAA	11.8	18.2	4.0	3.4	4.3
BHD	11.8	17.9	3.8	3.2	4.3
BKA	11.7	14.5	3.5	2.8	3.7
CA	11.6	14.2	3.4	2.6	3.8
DF	11.8	17.6	3.9	3.3	4.2
FA	12.0	20.2	4.1	3.8	4.7
LAD	12.1	22.4	4.3	4.0	5.0
LB	11.6	13.7	3.4	2.6	3.6
LLA	12.2	23.6	4.4	4.3	4.9
LLD	12.0	21.6	4.4	4.0	4.6
LRL	11.9	20.3	4.0	3.8	4.8
ND	11.6	15.3	3.6	2.9	3.8
PF	11.7	17.7	3.9	3.2	4.4
TA	11.8	19.0	4.0	3.7	4.4
TBA	12.4	29.7	4.7	4.9	5.7
TBD	12.5	28.8	4.6	4.9	5.5
TBR	12.5	30.2	4.8	4.8	5.7
TD	12.0	19.6	4.1	3.6	4.5
UB	11.7	14.6	3.5	2.7	3.7
all	**11.9**	**19.6**	**4.0**	**3.6**	**4.5**

TABLE II
Compression speeds, given in MB/s.

IV. Experimental Results

In Tables II and III we report results obtained by several standard image compression algorithms for the image dataset described in Section II. Results are given in terms of compression speed (Table II) and compression ratio (Table III), for each of the groups in the dataset as well as average results over all groups. The numbers are calculated as an average for all images contained in the group; since not all groups contain the same number of images the average results for all images may be slightly different from the average of all groups. Below, we briefly characterise the algorithms and implementations we used in this study:

- Lossless JPEG - former JPEG committee standard for lossless image compression [6]. The standard describes predictive image compression algorithm with Huffman or arithmetic entropy coder. We used the Cornell University implementation (version 1.0, `ftp://ftp.cs.cornell.edu/pub/multimed/ljpg.tar.Z`) which applies Huffman coding. The results are reported for the predictor function SV2 which resulted in the best average compression ratio for the dataset.
- JPEG-LS - standard of the JPEG committee for lossless and near-lossless compression of still images [3]. The standard describes low-complexity predictive image compression algorithm with entropy coding using modified Golomb-Rice family. The algorithm is based on the LOCO-I algorithm [14]. We used the University of British Columbia implementation (version 2.2, `ftp://ftp.netbsd.org/pub/NetBSD/packages/distfiles/jpeg_ls_v2.2.tar.gz`).
- JPEG2000 - a recent JPEG committee standard describing an algorithm based on wavelet transform image decomposition and arithmetic coding [4]. Apart from lossy and lossless compressing and decompressing of whole images it delivers many interesting features (progressive transmission, region of interest coding, etc.) [1]. We used the JasPer implementation by Adams (version 1.700.0, `http://www.ece.uvic.ca/~mdadams/jasper/`).
- PNG - standard of the WWW Consortium for lossless image compression [18]. PNG is a predictive image compression algorithm using the LZ77 [19] algorithm and Huffman coding. We used the `pnmtopng` implementation (version 2.37.6, part of the NetPBM 10.25 toolkit, `http://netpbm.sourceforge.net/`) compiled with libraries `libpng` (version 1.2.8, `http://libpng.sourceforge.net/`) and `zlib` (version 1.2.2, `http://www.gzip.org/zlib/`). The results are reported for the "sub" predictor function (filter), which resulted in the best average compression ratio for the dataset.
- CALIC - a relatively complex predictive image compression algorithm using arithmetic entropy coder, which because of its usually high compression ratios is commonly used as a reference for other image com-

pression algorithms [16], [17]. We used the implementation by Wu and Memon (`ftp://ftp.csd.uwo.ca/pub/from_wu/`).

images	L-JPG	JPEG-LS	JPEG2000	PNG	CALIC
ABD	2.83	3.86	3.48	3.06	3.76
BAA	3.03	4.12	3.73	3.28	4.04
BHD	2.86	3.81	3.41	3.05	3.75
BKA	2.50	3.11	2.85	2.52	3.10
CA	2.41	3.06	2.78	2.55	3.01
DF	3.03	4.04	3.68	3.20	3.99
FA	3.18	4.73	4.23	3.70	4.57
LAD	3.48	5.23	4.68	4.12	4.98
LB	2.36	2.92	2.65	2.41	2.88
LLA	3.75	5.71	5.09	4.27	5.52
LLD	3.64	5.34	4.79	4.06	5.18
LRL	3.24	4.71	4.19	3.66	4.56
ND	2.55	3.33	3.04	2.78	3.28
PF	2.94	3.96	3.59	3.27	3.89
TA	3.14	4.40	3.98	3.44	4.28
TBA	4.21	7.35	6.36	5.42	6.96
TBD	4.20	7.19	6.22	5.36	6.84
TBR	4.26	7.36	6.39	5.64	6.92
TD	3.21	4.49	4.08	3.46	4.36
UB	2.53	3.24	2.95	2.65	3.20
all	**3.04**	**4.21**	**3.79**	**3.35**	**4.11**

TABLE III
COMPRESSION RATIOS.

V. DISCUSSION

Among the tested algorithms the JPEG-LS is clearly the best when we consider the compression speeds listed in Table II. All other algorithms are noticeably slower - from 39% (Lossless JPEG) to 82% (PNG). Our aim in this study was to analyse popular ”standard” image compression algorithms; however we note, that there exist other methods with compression speeds over 2 times higher than JPEG-LS [2], [13]. The speeds of JPEG2000, PNG and CALIC are similar (CALIC is faster than the remaining two algorithms by 11% respectively 20%). Both CALIC and JPEG2000 use an arithmetic entropy coder in contrast to PNG which is based on faster techniques (LZ77 and the Huffman coding). Based on this we expected PNG to obtain compression speeds close to Lossless JPEG with Huffman coding. Therefore, the low speed of PNG is probably due to the implementation used. Looking at the results on a group by group basis, the best compression speeds were obtained for groups TBA, TBD, and TBR i.e. all three groups where the total body is captured. The worst compression speeds were achieved for groups BKA, CA, LB, and UB.

Considering the compression ratios from Table III we see that the ratios for JPEG-LS and CALIC are higher than those for JPEG2000 which in turn performs better than PNG and Lossless JPEG. While for various continuous tone grayscale images JPEG2000 has been reported as close to or little worse than JPEG-LS [10] our results indicate that for medical infrared images JPEG2000 is significantly worse than JPEG-LS which is the best performing algorithm. CALIC performs slightly worse than JPEG-LS but is also computationally much more complex. Looking at the results for each image group, the highest compression ratios are achieved for the three body groups TBA, TBD, and TBR while images of groups BKA, CA, LB, and UB are least compressible. Correlating this with the compressions speeds from Table II we see that there is a direct link between efficiency and efficacy.

Overall it is clear that JPEG-LS is the best performing algorithm for lossless compression of medical infrared images. Not only does it provide the highest compression ratios, it is also the fastest of the tested methods.

VI. CONCLUSIONS

In this study we analysed the performance of several lossless image compression algorithms, namely Lossless JPEG, JPEG-LS, JPEG2000, PNG, and CALIC, for a large set of medical infrared images. JPEG-LS was found to be the best performing algorithm which provides both the highest compression ratio and the fastest compression speed.

Analysing the images in the data set a bit closer we found that the actual number of intensity levels in those images is smaller than nominally possible; on average they contain 78 levels of 128 graylevels. As the impact of such histogram sparseness on image compression ratios is known to be high for some types of images [7] we are currently further investigating this for the case of infrared images.

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