FACULTY OF AUTOMATIC CONTROL, ELECTRONICS AND COMPUTER SCIENCE

PROGRAMME: CONTROL, ELECTRONIC AND INFORMATION ENGINEERING

Master Thesis

Improving the efficiency of lossless image compression using extensions of Part 2 of the JPEG 2000 standard

Author: Szymon Zosgórnik, BEng

Supervisor: Roman Starosolski, DSc PhD

Gliwice, September 2021

Załącznik Nr 2 do Zarz. Nr 97/08/09

O Ś W I A D C Z E N I E

Wyrażam zgodę/nie wyrażam* zgody na udostępnienie mojej pracy dyplomowej/rozprawy doktorskiej*

……., dnia ……..……

……..……

(podpis)

……

(poświadczenie wiarygodności podpisu przez Dziekanat)

** właściwe podkreślić*

Abstract

Lorem ipsum...

Keywords: loseless image compression, image processing, JPEG 2000, discrete wavelet transform, entropy estimation, multithreading, modern c++

Contents

Chapter 1. Introduction

1.1 Preface

The usage of digital images is constantly growing across whole world. There are multiple types of application where memory usage matters to the users. Image compression is a possible solution to this problem in some of these fields. For example it is mission critical component in medical and picture archiving and communication systems (PACSs). [14] There are two major types of such compression. The one is lossy variant and the other one is lossless. Applying lossy methods to the image can result in the occurrence of compression artifacts. However, there are applications where such disadvantage is negligible, e.g. natural images and photographs processing in Internet day-to-day usage. [3] On the other hand lossless image compression does not produce such artefacts, sacrificing some performance and bitrates optimizations. It is employed in mentioned before medical systems. Images used for the sake of diagnostics can be taken as an example. In some countries there are regulations that forbid applying lossy compression to such images. [14] Moreover, the usage of lossless variant is more desired when there exists some uncertainty whether information contained in the image can be discarded. In these scenarios not using any variant of compression can be the only subsitute of lossless one. [14]

Taking into account mentioned before reasons, some compression algorithms have been introduced as ISO standards. [14] Some notable examples of such papers are PNG, JPEG and JPEG 2000 (often written as JP2). The latter was orginally developed from 1997 to 2000 with the desire of expanding JPEG capabilities. The main feature of this standard is usage of discrete wavelet transform (DWT) instead of discrete cosine transform (DCT) which was introduced in the predecessor. [4] The other feature of JPEG 2000 are support for lossy and lossless compression. As can be described before, such compression is needed to be perfomed in mission critical systems such as medicine. Therefore, the JPEG 2000 standard is utilized in PACSs and Digital Imaging and Communications in Medicine DICOM standard. [14] This standard consist of 16 ISO parts which contain wide set of features. Some notable ones are core system coding and its extensions, motion images, testing and reference software. [4]

The successor of JPEG standard improved several aspects over its predecessor. With the usage of its algorithms, e.g. DWT, it was possible to improve compression performance over JPEG. Moreover, there are other improved areas with even greater importance. The few examples of such features are scalability and editability. [4] The JPEG 2000 standard supports both very low and very high rates of the compression. It comes crucial in applications that require such flexibility. Another main advantage of this standard is the ability of effective handling large range of bit rates. It allows to reduce number of steps taken in processing certain images in comparison to JPEG. As an example, reducing the number of bits in some image below certain amount using JPEG standard compliant solution requires reducing the resolution of the input at first. Only after this procedure encoding of the image can be applied. The JPEG 2000 standard supplies adequate feature named multiresolution decomposition structure which makes such transformation transparent and one step only. [4]

1.2 Objective of the project

The standard way of performing discrete wavelet transform (DWT) in the JPEG 2000 compliant with Part 1 is to decompose the image into subbands using a pair of low and high-pass filters. This decomposition is applied multiple times using higher DWT orders. The standard order which is used across whole industry is five. [10] [7] The Part 2 of the standard contains several types of extensions which can be applied to modify the encoding algorithm. For instance DWT can be modified in a way that makes decomposition of the image into subbands of different shapes possible. Moreover, the strict selection of the pair of filters imposed by Part 1 of the standard can be broken. However, the same pair has to be used for all subbands of the image. [10] The oter type of applicable modification is skipping some steps of discrete wavelet transform (SS-DWT). It is usually beneficial for processing non-photographic and screen content images. Another way of achieving improvement in terms of compression ratio is applying the reversible histogram packing. This type of extension significantly improves the ratio of compression when the histogram of the image is sparse. It means that unused levels appear between frequently used brightness levels. With the help of described Part 2 compliant extensions to the JPEG 2000 standard it is possible to adaptively adjust the transform for a specified image to improve the compression ratio. The result of this operation can still be correctly decoded by every decompressor which is compatible with the Part 2 of the JPEG 2000 standard.

The objective of the thesis is to develop, implement and test several form of heuristics which can determine the optimal transform in terms of compression ratio of the given image. Transform shall be compliant with the Part 2 of JPEG 2000. The heuristics shall be rather fast and use entropy as an estimation of the JPEG 2000 encoding. Moreover, they can be greedy and use trial and error approach to some extent. The implementation of the program shall be done in modern C++ to utilize such language capabilities as cross-platform threads. The main target of the application are multi-core CPU architectures. The result of the project work is a tool that quickly determines the transform for the specified image and invokes the JPEG 2000 encoder with selected transform. However, it is acceptable to achieve small time overhead in terms of the entire compression process. The resulting image shall come with the improvemnt of the lossless JPEG 2000 compression ratio.

1.3 Scope of the thesis

- Initial research in fields of image processing and compression, analysis of JPEG 2000 algorithm.
- More advanced research of algorithms such as DWT, SS-DWT, HP and JPEG 2000 implementation - Kakadu.
- Development of basic DWT implementation.
- Development of advanced 2D DWT implementation with possibility of skipping transformation of columns or rows.
- Setup of Continuous Integration system and implementation of DWT testing component
- Development of initial heuristics allowing to study the effects of DWT modifications compliant with the JPEG 2000 standard such as decompositions into subbands and usage of different filters
- Support of loading and storing both grayscale and color images.
- Initial implementation of multi-threaded heuristics.
- Conducting preliminary tests and selecting modifications or their variants to be included in the final heuristics.
- Development of multi-threaded optimized implementation of final heuristics.

- Research on final heuristics - comparison in terms of obtained compression ratio and time with: unmodified JPEG 2000, SS-DWT transformation and the transformation determined by an exhaustive search.

1.4 Thesis outline

At the beginning of this paper there is introduction to the domain problem of image processing and compression. Some methods of applying this kind of compression are described in Introduction. Moreover, objective and scope of the thesis are described there.

The last chapter is Summary which wraps up all results and makes some valuable conclusions. At the end there are appendices available such as technical documentation and list of used tables, listings, etc.

Chapter 2. Problem analysis

- problem analysis, problem statement

2.1 Discrete Wavelet Transform

2.2 Part 2 of the JPEG 2000

2.3 Computer architecture

2.4 Known solutions

- state of the art, literature research (all sources in the thesis have to be referenced)
- description of known solutions, algorithms

Chapter 3. Subject of the thesis

3.1 Solution to the problem

- solution to the problem proposed by the author of the thesis
- theoretical analysis of proposed solutions

3.2 Rationale of applied algorithms

- rationale of applied methods, algorithms, and tools

Chapter 4. Experiments

This chapter presents the experiments. It is a crucial part of the thesis and has to dominate in the thesis. The experiments and their analysis should be done in the way commonly accepted in the scientific community (eg. benchmark datasets, cross validation of elaborated results, reproducibility and replicability of tests etc).

4.1 Methodology

- description of methodology of experiments
- description of experimental framework (description of user interface of research applications – move to an appendix)

4.2 Data sets

- description of data sets

4.3 Results

- presentation of results, analysis and wide discussion of elaborated results, conclusions

Figure 4.1: Some caption.

Table 4.1: A caption of a table is **above** it.

	method						
			alg. 3			alg. 4, $\gamma = 2$	
ζ	alg. 1	alg. 2	$\alpha = 1.5$	$\alpha = 2$	$\alpha = 3$	$\beta = 0.1$	$\beta = -0.1$
0	8.3250	1.45305	7.5791	14.8517	20.0028	1.16396	1.1365
5	0.6111	2.27126	6.9952	13.8560	18.6064	1.18659	1.1630
10	11.6126	2.69218	6.2520	12.5202	16.8278	1.23180	1.2045
15	0.5665	2.95046	5.7753	11.4588	15.4837	1.25131	1.2614
20	15.8728	3.07225	5.3071	10.3935	13.8738	1.25307	1.2217
25	0.9791	3.19034	5.4575	9.9533	13.0721	1.27104	1.2640
30	2.0228	3.27474	5.7461	9.7164	12.2637	1.33404	1.3209
35	13.4210	3.36086	6.6735	10.0442	12.0270	1.35385	1.3059
40	13.2226	3.36420	7.7248	10.4495	12.0379	1.34919	1.2768
45	12.8445	3.47436	8.5539	10.8552	12.2773	1.42303	1.4362
50	12.9245	3.58228	9.2702	11.2183	12.3990	1.40922	1.3724

Chapter 5. Summary

5.1 Results

- synthetic description of performed work

5.2 Conclusions

- conclusions
- Has the objective been reached?

5.3 Future development

- Future development, potential future research

Appendices

Technical documentation

List of abbreviations and symbols

JPEG	Joint Photographic Experts Group
PNG	Portable Network Graphics
PACSs	Picture Archiving and Communication Systems
DICOM	Digital Imaging and Communications in Medicine
ISO	International Organization for Standardization
DCT	Discrete Cosine Transform
DWT	Discrete Wavelet Transform
SS-DWT	Skipped Steps Discrete Wavelet Transform
HP	Histogram Packing
N	cardinality of data set
μ	membership function of a fuzzy set
$\mathbb{E}$	set of edges of a graph
$\mathcal{L}$	Laplace transformation

Contents of attached CD

The thesis is accompanied by a CD containing:

- thesis (`pdf` file),
- source code of applications,
- data sets used in experiments.

List of Figures

List of Tables

Bibliography

[1] C++ reference. https://en.cppreference.com/. [Latest available: 12.07.2021].

[2] Cmake. https://cmake.org/. [Latest available: 12.07.2021].

[3] Image compression. https://en.wikipedia.org/wiki/Image_compression. [Latest available: 12.07.2021].

[4] Jpeg 2000. https://en.wikipedia.org/wiki/JPEG_2000/. [Latest available: 12.07.2021].

[5] Kakadu. https://kakadusoftware.com/. [Latest available: 12.07.2021].

[6] Python. https://www.python.org/. [Latest available: 12.07.2021].

[7] Touradj Ebrahimi Athanassios Skodras, Charilaos Christopoulos. The jpeg 2000 still image compression standard. *IEEE Signal Processing Magazine*, 2001.

[8] David A. Patterson John L. Hennessy. *Computer Architecture: A Quantitative Approach*. Elsevier, Incs, 2012.

[9] Scott Meyers. *Effective Modern C++*. O'Reilly Media, 2014.

[10] Touradj Ebrahimi Peter Schelkens, Athanassios Skodras. *THE JPEG 2000 SUITE*. John Wiley & Sons, Singapore Pte. Ltd., 2009.

[11] Roman Starosolski. Skipping selected steps of dwt computation in lossless jpeg 2000 for improved bitrates. *Plos one*, 2016.

[12] Roman Starosolski. A practical application of skipped steps dwt in jpeg 2000 part 2-compliant compressor. *Springer Link*, 2018.

[13] Roman Starosolski. Reversible denoising and lifting based color component transformation for lossless image compression. *Springer Link*, 2019.

[14] Roman Starosolski. Hybrid adaptive lossless image compression based on discrete wavelet transform. *Entropy*, 2020.

[15] Bjarne Stroustrup. *The C++ Programming Language*. Pearson Education, 2013.

[16] Bjarne Stroustrup. *A Tour of C++*. Pearson Education, 2013.

[17] D. Sundararajan. *Discretewavelet Transform: A Signal Processing Approach*. John Wiley & Sons, Singapore Pte. Ltd., 2015.

[18] Anthony Williams. *C++ Concurrency in Action*. Manning Publications, 2019.