Review Statement for David Bařina's Doctoral Thesis

"Lifting Scheme Cores for Wavelet Transform"

April 10, 2016

As the reviewer nominated by Brno University of Technology, I respectfully make the following statement concerning the doctoral thesis of Mr. David Bařina, submitted for the fulfillment of the requirements of the PhD degree in Computer Science and Engineering. I consider the following details of the thesis: the position in the research field, originality, and contributions, including also the candidate's publications.

This thesis investigates efficient computation of the two-dimensional discrete wavelet transform for image and video processing applications. The goal is to extend the state-of-the-art methods to perform the transform in a single loop, including also multi-scaling, using a compact streaming core. The work considers the SIMD extensions, the cache hierarchy of modern processors, and possibilities of parallel computing. One of the practical goals is to incorporate the approach into the JPEG 2000 compression chain. Robust image and video compression is one of the challenging bottle-neck problems in Computer Vision, especially due to an increasing amount of real-time streaming applications. Thus, the topic of the thesis is very well motivated. The main contribution is a novel formulation of a computation unit built over the lifting scheme technique. The candidate motivates the proposed core approach by describing shortcomings of the current approaches, and shows experimentally that the approach is computationally efficient as compared to the existing solutions in different platforms. The work contains comprehensive amount of evaluations.

As a conclusion, the topic is appropriate to the particular area of dissertation and it is up-to-date from the viewpoint of the present level of knowledge.

The thesis consists of eight chapters. In Chapter 1, the research field is shortly introduced, the focus of the work is defined, and the structure of the thesis is shown. The focus is to develop methods for computing the discrete wavelet transform by extending the existing single-loop methods to enable to deal with two-dimensional multi-scale decomposition and to efficiently utilize features of modern CPUs. The objectives should have been presented more clearly either as explicit research questions or as listed specific objectives. The needed research has been introduced well, but with too many short paragraphs. The applications could have been emphasized more as motivation.

In Chapter 2 the discrete wavelet transform is overviewed, including lifting scheme and implementation issues. The thesis focuses on the CDF (Cohen-Daubechies-Feauveau) 5/3 and 9/7 wavelets which are often used for image compression. Although the chapter is in general well written referencing could have been active, especially in case of equations. Moreover, the numbering of some figure citations is not chronological which occur also later in the thesis. For example, Fig 2.2. is cited in the text before Fig 2.1. Moreover, the figure should always appear after the citation,

not before. In Chapter 3, existing approaches of computing the two-dimensional scheme on different platforms consisting of GPPs, FPGAs, and GPUs are considered. Also in this chapter the candidate should have given more actively citations to references and presented the subfigures and the subfigures more chronologically. Comments like "In my opinion" should be avoided without clear justifications.

Chapter 4 discusses about lifting vectorization. Based on the existing solutions, the motivation of the thesis is considered in case of horizontal, vertical, and diagonal vectorization. The first contributions of the candidate are shown in this chapter in development in all types of vectorization so the candidate writes too modestly in the beginning. This work is based on joint publications, as also in the following chapters. It is good that these publications are cited although it is challenging to separate contributions, especially since also in the chapter referencing should have been more active. Equation 4.2 seems to be the same as Equation 2.9. There is no need for double definitions. In case of Table 4.1 it not clear what "algorithms" mean exactly.

The main contribution of the thesis, novel lifting scheme cores for wavelet transform, is presented in Chapter 5. More specifically, the candidate states that the contribution is a formulation of a computation unit built over the lifting scheme technique. This contributes to core organization, treatment of signal boundaries, and lifting schemes also for other wavelets than the CDF 5/3 and 9/7 wavelets, and parallel cores. The new formulation contain the ability to retain intermediate results through the introduced auxiliary buffers. The approach has been presented in details with many explanations and equations, some equations being very long. Thus, it would have been wise to present the summary of the approach and its variations as algorithms or flowcharts. Moreover, this would have been useful for presenting results later in the thesis. Referencing to the candidate's own publications is very limited. All the equations should have been presented fluently as part of sentences. The approach is extended to multiple dimension in Chapter 6, especially to two-dimensional cores. The computational benefits of the cores are shown. The references to the other approaches should be clear in comparisons. For example, "Sweldens1995" is without the reference. Also in Chapters 5 and 6 many figures appear too early, even two pages before citing in the text. This makes reading less comfortable.

Chapter 7 contains comprehensive performance evaluation and discussion, The candidate has carried out numerous experiments showing his excellent knowledge also about software and hardware issues: the SIMD vectorization and parallelization of the 2D transform for image processing, JPEG 2000, multidimensional decompositions, parallel processing on GPU, FPGA devices, and vectorization. The proposed core approach gave the most promising results. Discussion about parameter sensitivity has been omitted. The connection to Chapters 5 and 6 could have been better by naming the approaches exactly and summarizing them step by step. Moreover, Chapter 7 contains introductions and discussions which belong to Chapters 5 and 6 since method descriptions and experiments are partially mixed.

Conclusions are given in Chapter 8. The contributions are stated as five useful features of the approach. Discussion about future work could have been much deeper and larger.

Based on the considered matters, the work is original and contains a sufficient contribution to the area.

Related to the thesis, the candidate has published one journal article in Journal of Real-Time Image Processing and six conference papers, and there is one accepted conference submission. The journal is an internationally recognized journal with a high impact factor, and most of the conferences are well-known international conferences. The candidate has written several joint publications with other researchers, and thus, the candidate has proven to be able to co-operate efficiently with other scientists. According to Google Scholar, the candidate's h-index is 3 and there are 22 citations to the candidate's research work, showing that his publications have attracted other researchers.

As a conclusion, the doctoral thesis has been published at an appropriate level and the candidate has published actively.

Besides the clear merits of the thesis, there are also presentation shortcomings, including minor mistyping and misspelling. Although the thesis is well structured there are numerous very short paragraphs. The list of abbreviations is not in the alphabetical order and half of the used abbreviations are missing on the list. Moreover, what is the order of the list of symbols? It is very unusual to use "I" or "my" like "I have chosen" or "my work" in the scientific text although naturally research work done in a doctoral dissertation is very personal matter. The expressions "some" and "etc." should be avoided. Also the future tense "will" should be avoided when it is meant to say "would" or to use the present tense. For pleasant readability, a figure should be presented after it has been mentioned in the text, not before. This problem is enhanced since sometimes the chronological order of citations is missing (e.g., the figure numbering does not match to the citation order) and there is too much forward and backward referencing. A table caption should be before a table, not after a table. The presentation in the bibliography is not always uniform, and definitely submitted papers should not be presented in the list of references. Despite these presentation problems, in general, the candidate has written a well structured thesis which is comfortable to read.

The candidate has shown a good understanding of the key issues in the research field. The thesis clearly contains contribution to knowledge in the field of computer science and engineering. There are many references to related work, research problems are considered properly, and there are several scientific papers published based on the results of the thesis.

Based on the considerations presented in this review statement I conclude that the doctoral thesis meets the requirements of the proceedings leading to the PhD title conferment.

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