Załącznik 3

Autoreferat w języku angielskim

Summary of academic achievements

1. Name and surname: **Roman Włodzimierz Starosolski**

2. Diplomas and scientific degrees:

   a) **Ph.D. in Computer Science**
   Faculty of Automatic Control, Electronics and Computer Science, Silesian University of Technology, Ph.D. thesis: "Lossless image compression algorithms", supervisor: prof. dr hab. inż. Zbigniew J. Czech, reviewers: prof. dr hab. inż. Władysław Skarbek and prof. dr hab. inż. Konrad Wojciechowski, Honours Cum Laude, 2002

   b) **M.Sc. in Computer Science**
   Faculty of Automatic Control, Electronics and Computer Science, Silesian University of Technology, M.Sc. thesis: "Generation of stereoscopic images", supervisor: dr inż. Marek Błaszczyk, 1995

3. Information on the academic experience:

since 2002:	Assistant Professor, Institute of Informatics Silesian University of Technology
2009 – 2014:	Assistant Professor, Katowice School of Economics
2008 – 2009:	Assistant Professor, Department of Computer Science, Silesian Higher School of Computer Science and Medicine
2000 – 2002:	Assistant Lecturer, Institute of Informatics Silesian University of Technology
1995 – 2000:	Ph.D. student and Assistant Lecturer, Institute of Informatics Silesian University of Technology

4. Scientific achievement (according to the article 16, paragraph 2 of the Polish legal act dated on 14th March 2003, entitled Law on Academic Degrees and Title and Degrees and Title in the Arts):

   a) A series of thematically related articles, entitled: *Methods for improving the efficiency of image compression algorithms*

[rs1] R. Starosolski, "Simple Fast and Adaptive Lossless Image Compression Algorithm," *Software—Practice and Experience*, vol. 37(1), pp. 65–91, doi 10.1002/spe.746, 2007. /IF=0.542, 5-year IF=0.726, 10 pts of Polish Ministry of Science and Higher Education/

[rs2] R. Starosolski, "Parallelization of an adaptive compression algorithm using the reduced model update frequency method," *Theoretical and Applied Informatics*, vol. 19(2), pp. 103–115, 2007.

[rs3] R. Starosolski, "Compressing High Bit Depth Images of Sparse Histograms," in *International Electronic Conference on Computer Science (IeCCS 2007)*, T. E. Simos and G. Psihoyios, Eds., vol. 1060 of *AIP Conf. Proc.*, pp. 269–272, doi 10.1063/1.3037069. American Institute of Physics, USA, 2008. /Web of Science, 7 pts of Polish Ministry of Science and Higher Education/

[rs4] T. Bernas, R. Starosolski, J. P. Robinson, and B. Rajwa, "Application of detector precision characteristics and histogram packing for compression of biological fluorescence micrographs," *Computer Methods and Programs in Biomedicine*, vol. 108(2), pp. 511–523, doi 10.1016/j.cmpb.2011.03.012, 2012. /IF=1.555, 5-year IF=1.589, 25 pts of Polish Ministry of Science and Higher Education/

[rs5] R. Starosolski, “New simple and efficient color space transformations for lossless image compression,” *Journal of Visual Communication and Image Representation*, vol. 25(5), pp. 1056–1063, doi 10.1016/j.jvcir.2014.03.003, 2014. /IF=1.218, 5-year IF=1.420, 30 pts of Polish Ministry of Science and Higher Education/

[rs6] R. Starosolski, “Application of Reversible Denoising and Lifting Steps to LDgEb and RCT Color Space Transforms for Improved Lossless Compression,” in *Beyond Databases, Architectures and Structures (12th International Conference BDAS 2016)*, S. Kozielski et al. (Eds.), vol. 613 of *Communications in Computer and Information Science*, pp. 623–632, doi 10.1007/978-3-319-34099-9_48. Springer, Switzerland, 2016. /Web of Science, 10 pts of Polish Ministry of Science and Higher Education/

[rs7] R. Starosolski, “Application of Reversible Denoising and Lifting Steps with Step Skipping to Color Space Transforms for Improved Lossless Compression,” *Journal of Electronic Imaging*, vol. 25(4), pp. 043025-1–17, doi 10.1117/1.JEI.25.4.043025, 2016. /IF=0.616, 5-year IF=0.840, 20 pts of Polish Ministry of Science and Higher Education/

[rs8] R. Starosolski, “Application of reversible denoising and lifting steps to DWT in lossless JPEG 2000 for improved bitrates,” *Signal Processing: Image Communication*, vol. 39(A), pp. 249–263, doi 10.1016/j.image.2015.09.013, 2015. /IF=1.602, 5-year IF=1.530, 25 pts of Polish Ministry of Science and Higher Education/

b) Elaboration on the scientific goal of the enlisted articles and achieved results, along with their potential applications.

4b.1 Introduction

The habilitation achievement has been presented in a form of a series of 8 related articles. The series contains 5 papers published in the journals indexed in the Journal Citation Reports (JCR) database, one paper in a journal not indexed in JCR and 2 conference papers, which are indexed in Web of Science. According to the declarations of my co-authors, attached to the application, my contribution to the paper [rs4] is 40%, whereas I am the sole author of all the other papers. Considering the co-authors' contributions, the weighted impact factor (IF) of the papers included into the series equals 4.582, the 5-year IF equals 5.152, and the number of points assigned by the Polish Ministry of Science and Higher Education is 112. These papers, according to the Web of Science Core Collection, were cited 42 times (28 times excluding self-citations). Selected bibliometric data on the papers from the series and on all my papers published after obtaining the doctoral degree are presented in Tables 1, 2, and 3.

The presented series of articles, except for [rs4], concerns methods of lossless image compression. In [rs4], a reversible histogram packing (HP) method was employed in a lossy image compression algorithm. The primary aim of the research described in the above-mentioned papers was to improve the efficiency of image compression algorithms in respect of the following features: the compression ratio, complexities (time and memory) of the compression and decompression algorithm, and in the case of lossy compression the quality of the decompressed image. I paid a special attention to the usefulness from a practical standpoint of the developed methods. I strived

Table 1: Articles included into the series.

		Year	Contribution (%)	IF	5-year IF	Ministry points	Cited*	Cited**
(1)	[rs1]	2007	100	0.542	0.726	10	21 (18)	36
	[rs4]	2012	40	1.555	1.589	25	5 (2)	7
	[rs5]	2014	100	1.218	1.420	30	9 (6)	23
	[rs7]	2016	100	0.616	0.840	20	—	0
	[rs8]	2015	100	1.602	1.530	25	0 (1)	4
(2)	[rs2]	2007	100	—	—	—	—	2
(3)	[rs3]	2008	100	—	—	7	6 (2)	10
	[rs6]	2016	100	—	—	10	0 (0)	1

(1) — articles in JCR journals
(2) — articles in other journals
(3) — conference papers
* — according to Web of Science Core Collection (without self-citations in the brackets); the paper [rs7] has not yet been indexed in the Web of Science
** — according to Google Scholar

Table 2: Impact factor, according to JCR, of all my papers and of the papers included into the series, computed considering the year of publication (or year 2015 in the case of [rs7]).

Papers	IF		5-year IF	
	total	weighted	total	weighted
Included into the series	5.515	4.582	6.105	5.152
All	7.036	4.962	7.693	5.549

to obtain an improvement of a selected algorithm's feature that is not accompanied by significant worsening of other features, I prepared implementations of methods I developed and made them publicly available[1], I filed 3 patent applications and was granted one patent.

The reminder of this summary of academic achievements is organized as follows. Section 4b.2 contains an introduction to the image compression. Section 4b.3 characterizes the main results obtained while preparing the doctoral dissertation—these results are presented as an introduction to the next section of this summary of academic achievements and are not a part of the habilitation achievement. The research on a simple, fast and adaptive lossless image compression algorithm is described in section 4b.4; this is a continuation of the work started in the course of the doctoral dissertation. Sections 4b.5–4b.7 describe research that was started after completing the Ph.D. Section 4b.5 describes results of employing the HP method in lossless and lossy image compression. In section 4b.6 I describe the research on methods of los-

[1] implementations are available from `http://sun.aei.polsl.pl/~rstaros/index.html`

Table 3: Selected bibliometric data of all the papers; retrieved on 25 November 2016.

Database	Number of papers	Citations	Citations excluding self-citations	*h*-index
Web of Science Core Collection*	15	56	40	5
Google Scholar	34	174	*ND*	7

* — the paper [rs7] has not yet been indexed in the Web of Science

sless color image compression that originate from simple color space transforms. This section presents, in my opinion, my most interesting method, i.e., the reversible denoising and lifting step (RDLS) method. In the next section (4b.7) I describe the application of RDLS to the discrete wavelet transform (DWT) employed in the JPEG 2000 algorithm for lossless grayscale image compression. Section 4b.8 summarizes the most important achievements described in papers contained in the presented series of articles. Next, on page 19, there is a list of the cited publications that are not authored by me or were published before completing my doctoral dissertation; references to these publications are denoted by a reference number, e.g., [1]. References to my publications from the presented series of articles are denoted by an article number with the "rs" prefix, e.g., [rs1]. Section 5 contains an overview of my other research. It also includes the list of completed research and research-and-development projects and (in Section 5a.6) the list of publications published after completing Ph.D. that are cited in this summary of academic achievements, but were not included in the series of articles. References to these publications are denoted by a publication number with the "oth" prefix, e.g., [oth1].

4b.2 Image compression

This section contains a brief introduction to data and image compression. For a more detailed description of basics, algorithms, and methods of data and image compression the reader is referred to books [1–4]. Compression algorithms reduce sizes of data sets, e.g., data sets containing texts or images. General-purpose algorithms are denoted as universal; usually such algorithms were originally aimed at text compression. Among universal algorithms there are dictionary and statistical algorithms, the latter may be based on sophisticated adaptive data models (prediction by partial matching [5, 6], context tree weighting [7]), and algorithms based on the Burrows-Wheeler transform [8, 9].

Since in contemporary image compression the statistical algorithms are the most commonly exploited, below I describe selected terms and methods concerning these algorithms. In statistical algorithms, based on probability distribution of symbols, we assign codewords of variable lengths to symbols. Informations based on which we determine the probability distribution are collected by a data model. If the model estimates conditional probabilities, i.e., if the specific symbol's context is considered in determining symbol's probability, then it is the context model and the number of preceding symbols used as a context is called the order of the model; otherwise the model is memoryless. In image compression, as opposed to universal statistical algorithms, the context of a specific symbol usually does not consist only of symbols preceding it. The data model may adapt to characteristics of the processed data in a couple of ways (fixed, static, or adaptive). In adaptive algorithms, using a model built for all the already processed symbols we encode specific symbol immediately after reading it; after encoding the symbol we update the data model.

Algorithm for encoding a given symbol based on probability distribution of symbols is called the entropy coder. Faster entropy coders use prefix codes (Huffman codes [10], Golomb codes [11], etc.) that assign to symbols binary codewords of integer lengths. In the arithmetic coder a single bit may be en element of a codeword of more than one symbol [12].

The compression ratio is the primary measure of compression effects. In the case of image compression it is expressed in bits per pixel; it is obtained by dividing the length of the compressed image (expressed in bits) by the number of pixels in the image; therefore, it is directly proportional to the size of the compressed image.

In image compression we may exploit lossy algorithms, which obtain compression ratios several times better, than lossless algorithms. In some applications, however, discarding of any information contained in an image is not acceptable even if the resulting loss of image quality is not directly noticeable. Lossless image compression, among others, is employed for medical images used for diagnostic purposes (in some cases lossy compression of such images is forbidden by law [13, 14]), for images that are considered documents, and for images acquired at a great cost [15]. Furthermore, we have to use lossless image compression when we are unsure whether discarding information contained in the image is applicable or not, which happens frequently when transmitting images over the network or directly from the acquisition device. My research was mainly focused on lossless algorithms and lossless variants of algorithms supporting both the lossless and the lossy compression.

The research described in the presented series of articles concerns compression of color and grayscale images. In the latter case, the image pixel is a nonnegative integer and its value denotes pixel's brightness (intensity). The range of pixel values (the number of grayscale levels) usually does not exceed 2^{16}. The image is of N bit depth (it is an N-bit image), when the size of the range of pixel intensities is 2^N. We say that the image is of high bit depth if the image depth is 12 bits per pixel, or more; if the depth is about 8 bits per pixel, or less, then it is a low bit depth image. The pixel of a color image is a 3-element vector. The elements of the vector represent brightness of image components and interpretation of these components is implied by the color space of the image. E.g., components of the RGB color space denote brightness of primary colors: red (R), green (G), and blue (B).

We could use universal algorithms to compress images, but for several reasons images are hard to compress for these algorithms. As opposed to texts, images are 2-dimensional data, the range of pixel intensities may be significantly larger than the alphabet size of a typical text, and images contain noise added to the image during the acquisition process that makes modeling less effective. Furthermore, the fact that the intensities of neighboring image pixels are highly correlated is not directly exploited by universal algorithms. Image compression algorithms employ techniques used in universal statistical compression algorithms. However, prior to statistical modeling and entropy coding the image data is transformed to make it easier to compress.

In efficient image compression we use two approaches: predictive coding and transform coding. In a predictive algorithm, we use the predictor function to guess the pixel intensities and then we calculate the prediction errors, i.e., differences between actual and predicted pixel intensities. Next, we encode the sequence of prediction errors, which is called the residuum (the process of obtaining the residuum is called the decorrelation). For typical natural images, i.e., images acquired from real-world scenes available to the unaided human eye, entropy of the probability distribution of residuum symbols is significantly smaller than entropy of the probability distribution of image pixels. Fast and simple image compression algorithms are constructed with the use of decorrelation, e.g., FELICS [16], JPEG-LS [17, 18], or my algorithm described in Section 4b.4.

Another method of making the image data easier compressible is to use a two-dimensional transforms, such as discrete cosine transform (DCT), which is exploited in a couple of standard image compression algorithms, e.g., JPEG XR [19, 20], or DWT that is exploited by JPEG 2000 [21, 22]. In transform algorithms, instead of pixel intensities, we encode a matrix of transform coefficients. The transform is applied to the whole image, or to an image split into fragments. Entropy of transformed coefficients is significantly smaller than entropy of image pixels, thus the transformed image is easier to compress. Image pixels are stored as integer numbers and also the matrix of transformed coefficients is encoded as integers. The transform for lossless compression has to be reversible considering that the transformed components are stored using integers (it has to be integer-reversible). An example of such transform (a variant of DWT) is presented in Section 4b.7.

In transmission and archiving of color images the most commonly used color space is RGB. This space is convenient for presenting an image on the screen, but since components of the RGB color space are highly correlated, other spaces are better for compression. The most common approach to color image compression is to compress independently the image components (i.e., images consisting of given component of all the image pixels) as if they were grayscale images. The compression is preceded by transforming image data from RGB to some less correlated color space. Naturally, for lossless compression the color space transform has to be integer-reversible; examples of such transforms are presented in Section 4b.6.

4b.3 Work done before completing Ph.D.

Two algorithms of lossless compression of 8-bit grayscale images (dictionary algorithm [23] and statistical algorithm [24]) were the main results of my Ph.D. dissertation. The statistical algorithm, denoted here as FRALIC, achieved better results—good compression speeds and compression ratios. However, FRALIC it was not feasible for compressing high bit depth images (among others, many modalities of medical images usually are of high bit depths). It's another disadvantage was low performance in the case of noisy images.

In FRALIC, a sequence of residuum symbols, obtained using a simple linear predictor, was encoded using an entropy coder exploiting a family of limited-codeword-length prefix codes (a variant of Golomb codes [11]). An adaptive data model was based on the data model from the FELICS algorithm [16], but compared to this algorithm the model of FRALIC was quite sophisticated. At the beginning of compression all the contexts were grouped in a single collective bucket (probability distribution was estimated jointly for all the contexts contained in the bucket)—in effect, the model was memoryless. Then, as compression proceeded, larger buckets were subsequently divided into smaller ones until the minimal bucket size was attained—as compression proceeded, the memoryless model became the context model. To improve the compression speed I proposed the reduced update frequency method (RUF), which is described in Section 4b.4.1.

The effects of a couple of methods exploited in FRALIC seemed promising. Before completing the Ph.D. dissertation I developed an improved prefix code family T3. As opposed to the code family used in FRALIC, it is well suited for encoding of high bit depth images. The T3 family is a limited-codeword-length variant of Golomb-Rice codes [11, 25]. This variant is described in detail in [oth3], where it is denoted as „proposed". After completing the Ph.D., besides starting new research topics, I continued the work on methods employed in FRALIC; results of this work are described in Section 4b.4.

4b.4 Simple, fast and adaptive lossless image compressor

The simple, fast and adaptive lossless image compressor (SFALIC), described in the publication [rs1], is designed for medical and natural continuous tone grayscale images of depths of up to 16 bits. I developed SFALIC in a result of the research project „An analysis of fast and adaptive lossless image compression algorithms applied to medical and natural continuous tone images" (2003–2005, Polish Ministry of Science and Informatization, nr. 4T11C 032 24). This project was, in turn, a follow-up of the research described in Section 4b.3 that was done before completing my Ph.D.

In SFALIC, similarly to FRALIC, a sequence of residuum symbols, obtained using a simple linear predictor, is encoded using an entropy coder exploiting a family of limited-codeword-length prefix codes, however, a different family (the T3 family) was used. Also in the SFALIC algorithm, in order to reduce the complexity of compression and decompression, the RUF method was employed. In research done later (described in Section 4b.4.1) I showed, that RUF allows to further improve the speed of an adaptive algorithm by exploiting fine- and medium-grained parallelism. The most significant differences between SFALIC and its predecessor are the code family and the data model.

The data model of the SFALIC algorithm is based on the model from FRALIC [24]. In the new model a certain shortcomings of the previous model were eliminated. As a result, the new model is well suited for compression of high bit depth images and noisy images. Also, despite being actually simpler than its predecessor, it works well at the beginning of compression, before adapting to the data actually being compressed. Thanks to utilizing another code family, improving the algorithm required introducing changes that in fact are not large. For instance, after introducing a new method of selecting a code from the family (when, according to informations from the data model, several codes are equally good), the complicated mechanism of variable number of context buckets could be given up. Despite the fact, that differences from models of FELICS and FRALIC in fact are not large, thanks to these changes and to employing the T3 family, I obtained an algorithm that is actually used in practice.

Within the 4 T11C 032 24 project I designed and implemented the freely available implementation of SFALIC, that from a practical standpoint is my most important original design, constructional and technological achievement. As a result of the research done using the above implementation for medical and natural images, I found that SFALIC was especially good for:

- big images, since it compresses them with the very high speed (it needs less than 50 CPU cycles per byte of image),
- natural images of 16-bit depth, since it obtains for them very good compression ratio—its ratio differs by couple percent from the state-of-the-art,
- noisy images, since as opposed to the other algorithms, it causes almost no data expansion even if the image contains nothing, but noise.

Due to advantages of SFALIC, there is at least one significant practical application of this algorithm in industry. Extended version of SFALIC, named QUIC, was included into the SPICE remote desktop protocol of the Red Hat Enterprise Virtualization platform. The implementation of QUIC distributed by the Red Hat company is directly based on my source codes of SFALIC. Unmodified SFALIC source codes developed by me constitute the majority of QUIC sources. For an efficient processing of color and computer-generated images, the SFALIC algorithm was extended with a color space transform and a simple mode of encoding of sequences of same pixels. Since SFALIC and its implementation had been published I received several queries about the possibility of using my SFALIC implementation in telematics and image compression. Each time I assented, but except for the application by Red Hat, I do not know any further results of these projects.

4b.4.1 Application of the reduced update frequency method for parallelization of an adaptive algorithm

Modeling and coding is the most complex part of many adaptive compression algorithms; it is also an inherently serial process. Fig. 1.A presents sample adaptive compression algorithm, which uses a parametric code family and a memoryless data model. In this example, encoding of the M symbol is done, as in SFALIC, in the following steps:

i. based on informations from the data model, determine the coding parameter k (i.e., the number of code from the parametric code family; in a general case the probability distribution of symbols is the determined coding parameter),
ii. generate the codeword W for the symbol M in code k, and
iii. output the codeword W.

Each time after encoding of the symbol we update the data model in order to make the model include informations on all the already processed symbols. The RUF method (Fig. 1.B) is a modification I proposed for the FRALIC algorithm; it improved the modeling speed at the expense of a negligible, from a practical standpoint, worsening of the quality of modeling. Each time after updating the model we select (in a pseudo-random way, to permit decoder select the same value) the number of model update operations to be skipped before the next update. We may change the update frequency by changing the range of pseudo-random numbers. This way we control the speed of model adaptation and the computational time complexity of the algorithm (note, that the complexity order of an algorithm is not altered). In the case of SFALIC, the RUF method resulted in increasing the compression speed 3 times at the cost of worsening the compression ratio by 0.5%.

In the research described in the publication [rs2] I noticed, that RUF allows to parallelize the compression algorithm. Between the consecutive model updates a certain number of symbols gets encoded based on the model that contains exactly the same informations, which allows to perform in parallel the most of the symbol ending operations. The idea of parallelization is presented in Fig. 1.C. I found that this method, for the Itanium 2 processor and the SFALIC algorithm, allows to increase the speed of coding and modeling by roughly 50% by exploiting the fine-grained parallelism. Further estimations showed, that this method allows also to exploit the medium-grained parallelism in a significantly larger extent.

4b.5 Applications of the histogram packing method

Histograms of certain images are sparse, i.e., the number of intensity levels actually used by image pixels is smaller, than implied by the image nominal bit depth. Among others, thanks to works by Pinho (e.g., [26, 27]), the adverse effect of histogram sparseness on image compression ratios is well known in the case of low bit depth images. When researching the SFALIC algorithm I noticed, that certain types of high bit depth images, like medical CT and MR images have sparse histograms. Also, certain routine image processing methods, e.g., gamma correction or contrast adjustment, may make the histogram sparse.

Compression ratios attained by predictive and transform image compression algorithms may be significantly improved by transforming sparse histogram images before compression into dense histogram images, i.e., by applying HP. Naturally, to make the compression and decompression process reversible, the information describing how to

A)
```
loop
  read symbol M
  using model estimate coding parameter k for symbol M
  generate codeword W of symbol M in code of rank k
  output codeword W
  update model with symbol M
endloop
```

B)
```
delay := random(range)
loop
  read symbol M
  using model estimate coding parameter k for symbol M
  generate codeword W of symbol M in code of rank k
  output codeword W
  if delay = 0 then
    update model with symbol M
    delay := random(range)
  else
    delay := delay-1
  endif
endloop
```

C)
```
delay := random(range)
loop
  read symbols M_0 ... M_delay
  parfor i:=0 to delay
    using model estimate coding parameter k_i for symbol M_i
    generate codeword W_i of symbol M_i in code of rank k_i
  endparfor
  output codewords W_0 ... W_delay
  update model with symbol M_delay
  delay := random(range)
endloop
```

Figure 1: A) Adaptive modeling and coding, B) The RUF method, C) The idea of fine-grained parallelization of adaptive modeling and coding using the RUF method.

expand the histogram after decompressing an image, has to be encoded along with the compressed image. In the research described in the publication [rs3] I analyzed methods of high bit depth sparse histogram image compression and found, that HP results in significant improvement of the compression ratio; the improvement may be as high as 50%. However, for the high bit depth image the efficient encoding of the information describing how to expand the histogram after decompressing an image can be a problem. I tested several encoding methods and proposed a new method well suited for high bit depth images.

I also exploited the HP method in lossy compression of high bit depth light microscopy images. Cooperation in this topic was proposed to me by dr. Tytus Bernaś from Nencki Institute of Experimental Biology. He developed the method of histogram binning (HB) that allows to discard insignificant, from a statistical standpoint, intensity levels from the light microscopy image. HB was performed based on the model of acquisition device's detector precision characteristics (DPC) and using actual image acquisition parameters. The DPC model, in turn, was constructed with the use of experimentally determined properties of the acquisition device (like the amount of additive and Poisson noise). HB is a lossy transform, however, it is aimed at minimizing the effects of discarding of part of the information contained in an image on results of analyses of the transformed image. I proposed to combine HB and HP, which resulted in the histogram binning packing algorithm (HBP) that conserves well the significant information contained in a light microscopy image. The research described in publication [rs4] showed, that effects of the lossless compression of images processed with HBP are better compared to direct application of lossy compression.

4b.6 Reversible transforms of color image components

The RDLS (reversible denoising and lifting step) method is my most interesting research result obtained after completing Ph.D. The idea of RDLS was born as a result of the research concerning reversible color space transforms.

There are several reversible color space transforms that are well known and practically exploited; they allow to improve the compression ratios of lossless image compression algorithms. The RCT transform from the JPEG 2000 standard is often used; it is presented below with its inverse:

$$\begin{aligned} Yr &= \lfloor (R+2G+B)/4 \rfloor \\ Ur &= R-G \\ Vr &= B-G \end{aligned} \quad \iff \quad \begin{aligned} G &= Yr - \lfloor (Ur+Vr)/4 \rfloor \\ R &= Ur+G \\ B &= Vr+G \end{aligned} \quad , \tag{1}$$

where $\lfloor x \rfloor$ denotes the greatest integer not exceeding x, whereas Yr, Ur and Vr are components of the color space obtained after applying RCT.

Color space transforms that are commonly used in algorithms and standards of lossless image compression are constructed based on transforms for lossy compression, that in turn are based on KLT (Karhunen-Loève Transformation) computed for representative image sets. Certain such transforms exploit modular arithmetic in order to avoid the increase of the components' dynamic ranges, which may be beneficial for compression ratios.

KLT optimally decorrelates the image, however, although the general idea of improving the compression ratio by reducing the inter-component correlation is correct, there is no reason to assume that the optimal compression ratio can be attained by making the correlation equal to 0. Especially in the case of lossless compression, noise contained in components significantly impacts the compression ratios. The primary source of noise in an image is its acquisition process, for different components such noise is independent. Color space transform may result in propagating noise among components. Since most lossless image compression algorithms compress transformed components independently, then the amount of noise that has to be losslessly encoded may get increased. Considering the above premises I departed from a traditional method of constructing transform for lossless image compression based on KLT. Based on observations of actual lossless compression ratios of individual image components obtained with simple transforms or untransformed I proposed new simple transforms. Preliminary research showed that the transform denoted here as the RDgDrb:

$$\begin{array}{ll} R & = R \\ Dg & = R - G \\ Drb & = R - B \end{array} \iff \begin{array}{ll} R & = R \\ G & = R - Dg \\ B & = R - Drb \end{array} \tag{2}$$

may for natural images result in compression ratios that are better than in the case of established transforms including RCT. I was granted a patent on a method and system of image processing that exploits the RDgDrb transform [oth16].

During further research, which is described in publication [rs5], among others I proposed the RDgDb transform:

$$\begin{array}{ll} R & = R \\ Dg & = R - G \\ Db & = G - B \end{array} \iff \begin{array}{ll} R & = R \\ G & = R - Dg \\ B & = G - Db \end{array} . \tag{3}$$

In the case of standard test image sets and standard image compression algorithms (JPEG-LS, JPEG 2000, and JPEG XR), this transform and its modular variant mRDgDb proved to be better than other transforms with respect to the obtained compression ratios and the transform complexities, although they removed the inter-component correlation in a smaller extent than RCT or KLT. In my research, besides standard transforms and KLT (its reversible and irreversible variants, constructed for each image individually), I also included simple transforms being composed of permutations of color space components and transforms: RDgDrb and RDgDb (regular and modular variants). I filed a patent application on the RDgDb transform [oth14]. The application was accepted by the Polish Patent Office, published in newsletter of the Office, and currently is pending.

Transforms like RCT and RDgDb are performed as sequences of lifting steps (LS). In each LS of a transform a single pixel component is modified by adding to it a linear combination of other components of the same pixel; the sum may be negated. A transform performed as a sequence of lifting steps has advantageous properties: it may be computed in-place, it is integer-reversible, and it is easily and perfectly invertible. Let's see RCT presented in a form of sequence of LS:

$$\begin{array}{ll} \text{step 1:} & C_1 \leftarrow C_1 - C_2 \\ \text{step 2:} & C_3 \leftarrow C_3 - C_2 \\ \text{step 3:} & C_2 \leftarrow C_2 + \lfloor (C_1 + C_3)/4 \rfloor \end{array} \iff \begin{array}{ll} \text{step 1:} & C_2 \leftarrow C_2 - \lfloor (C_1 + C_3)/4 \rfloor \\ \text{step 2:} & C_3 \leftarrow C_3 + C_2 \\ \text{step 3:} & C_1 \leftarrow C_1 + C_2 \end{array} , \tag{4}$$

where $C1$, $C2$ and $C3$ denote the R, G, and B components of the untransformed image, respectively, as well as the Ur, Yr, and Vr components, respectively, that are obtained in place of R, G, and B after the transform. Noise may get propagated to the component being modified in the current LS from other components used in this LS. For instance, in step 1, that modifies $C1$ in order to reduce correlation between

$C1$ and $C2$, noise from $C2$ is added to $C1$ (assuming that noise in these components is independent). LS may be generalized as:

$$C_x \leftarrow C_x \bigoplus \mathrm{f}(C_1, \ldots, C_{x-1}, C_{x+1}, \ldots, C_m), \tag{5}$$

where C_i is the i-th component of the pixel, C_x is the component which is modified by the step, and m is the number of components in the color space. The step is reversible if the function f is deterministic and the operation $\bigoplus$ is reversible.

In order to limit the propagation of noise, I proposed to modify the LS by denoising of arguments of its function f. The modified LS is denoted as RDLS:

$$C_x \leftarrow C_x \bigoplus \mathrm{f}(C_1^d, \ldots, C_{x-1}^d, C_{x+1}^d, \ldots, C_m^d), \tag{6}$$

where C_i^d is the denoised i-th component of the pixel; note that denoising is not an in-place operation (computing the function f argument C_i^d does not alter C_i). For denoising of C_i any component of any pixel may be used, but the C_x of the pixel to which the RDLS is being applied. For example, see the RCT transform modified using RDLS, i.e., the RDLS-RCT transform:

$$\begin{array}{ll} \text{step 1:} & C_1 \leftarrow C_1 - C_2^d \\ \text{step 2:} & C_3 \leftarrow C_3 - C_2^d \\ \text{step 3:} & C_2 \leftarrow C_2 + \lfloor (C_1^d + C_3^d)/4 \rfloor \end{array} \iff \begin{array}{ll} \text{step 1:} & C_2 \leftarrow C_2 - \lfloor (C_1^d + C_3^d)/4 \rfloor \\ \text{step 2:} & C_3 \leftarrow C_3 + C_2^d \\ \text{step 3:} & C_1 \leftarrow C_1 + C_2^d \end{array} . \tag{7}$$

The diagram in Fig. 2 presents operations performed by consecutive steps of forward and inverse RDLS-RCT. Effects of these operations on components of a sample image contaminated with impulse noise are presented in Fig. 3. The median filter with 3×3 pixel window was used for denoising; Fig. 3 present also the denoised temporary components produced while computing RDLS-RCT. As we can see, the components obtained after RDLS-RCT (Fig. 3.G–I) contain significantly less noise, then components obtained after unmodified RCT (Fig. 3.J–L), therefore, we may expect better compression ratios in the case of the RDLS-RCT transform.

In the technical report [oth12] I described the preliminary research stage, in which RDLS was applied to the simple RDgDb transform. I filed a patent application on a compression method exploiting RDLS [oth15]. The application was published in the newsletter of the Polish Patent Office, and currently is pending. In publications [rs6] and [rs7] I describe the research on several color spaces modified using RDLS (RCT, YCoCg-R [28], RDgDb, and LDgEb [rs5]), as well as methods of efficient selection of denoising filters for a given image. The latter methods are based on a heuristic and a fast entropy estimator of compression effects I proposed. The best effects were obtained for the RDLS-modified RDgDb transform (RDLS-RDgDb) by exploiting linear denoising filters. This way, for 2 out of the 6 investigated test image sets I obtained the compression ratio improvement exceeding 5%. These 2 sets contained images in optical resolutions of acquisition devices that where unprocessed or processed in a minimal extent only.

Application of RDLS is a substantial modification of the lifting-based transform. The modified transform is not a color space transform anymore (as color space transform may be done for each pixel independently of others), it requires finding proper denoising filters, and signaling them to the decompressor. The RDLS-modified transform is more general than the original one. By employing special filters we may obtain, as a special case of the RDLS-modified transform, the unmodified transform or skip the transform; entire transform or selected steps of it may became unmodified

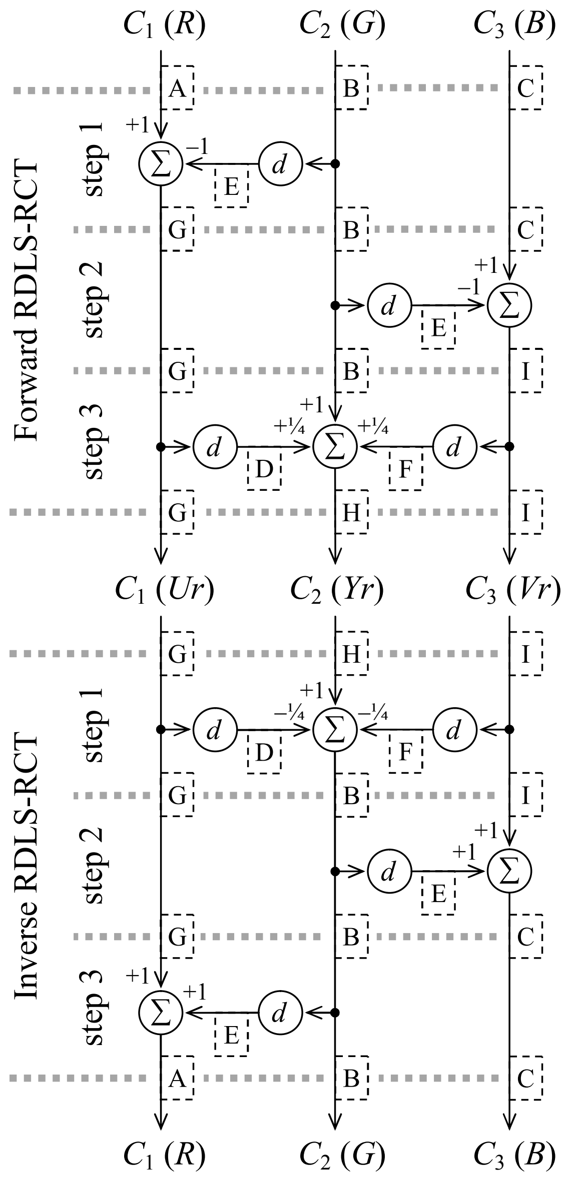

Figure 2: Example of forward and inverse RDLS-RCT. $\sum$—weighted sum of components, d—denoising of a component, dashed lines surround labels of Fig. 3 panels with the transformed component of a sample image.

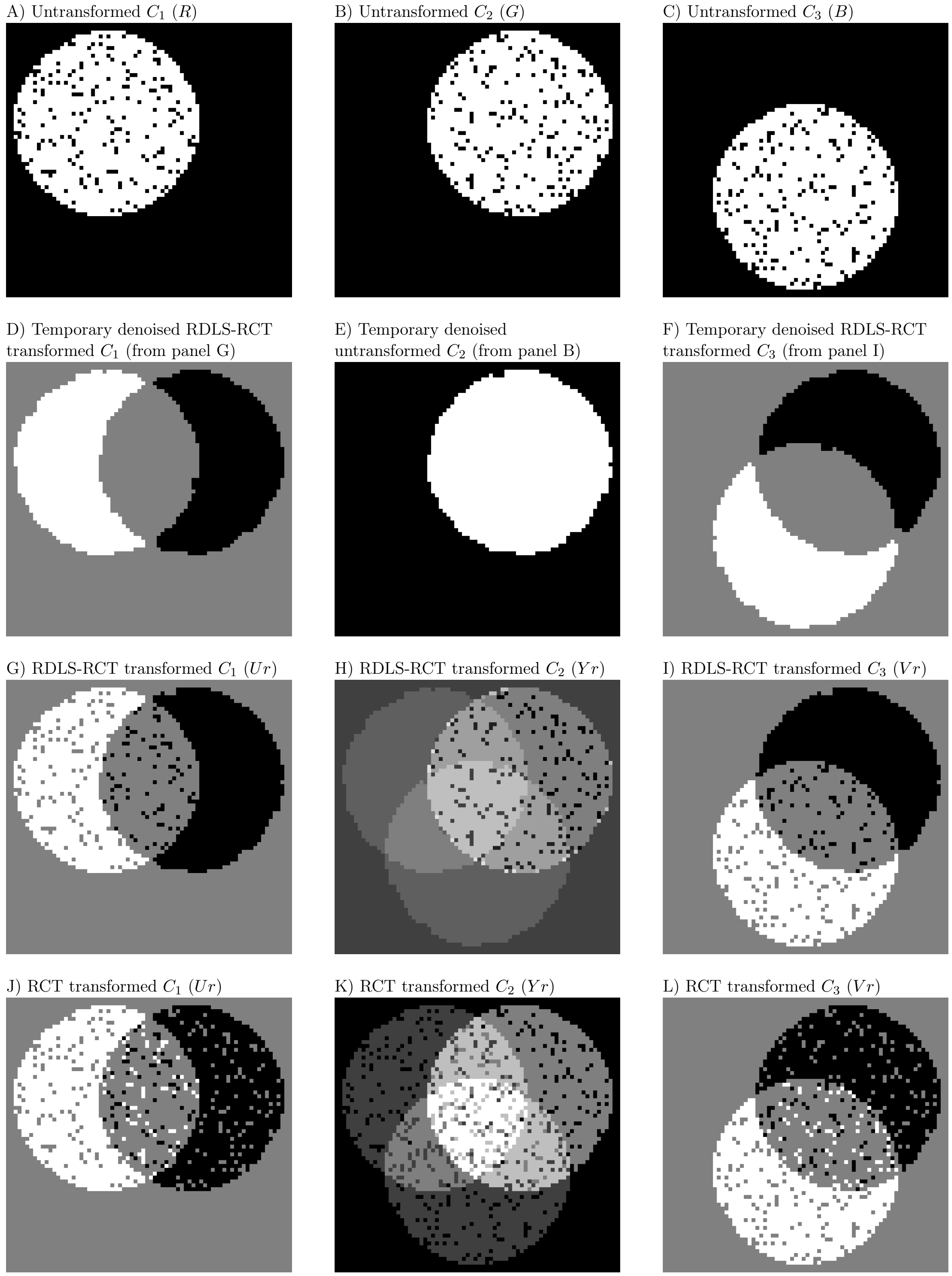

Figure 3: Effects of RCT and RDLS-RCT on components of a noisy image. (A–C) Untransformed components of the original image, (D–F) temporary denoised components created while computing RDLS-RCT, (G–I) RDLS-RCT transformed components, and (J–L) RCT transformed components; image sizes are 74×71 pixels, transformed components are presented normalized to the dynamic range of original ones.

or skipped. RDLS connects domains that until now were separate: the lossless compression and the inherently lossy denoising. Furthermore, application of RDLS is a general method applicable to other lifting-based transforms, not only to color space transforms. In the next section I describe an application of RDLS to DWT.

I plan to continue research on RDLS-modified color space transforms. I expect to attain significant, form a practical standpoint, further compression ratio improvements by selecting for an image not only the denoising filters but also the RDLS-modified color space transform. Compression of RAW files appears especially promising, these files contain untransformed image data acquired by a device's sensor and accompanied with parameters of the acquisition process. Instead of using a heuristic for determining the denoising filters I plan to employ filters based on the image acquisition parameters and a model similar to DPC (I have already done, in cooperation wit dr. Bernaś, a research on such a filter [oth1]). Out of various test image sets the best effects of RDLS application were obtained for images images, characteristics of which is in many ways similar to RAW files. RAW files contain data needed to apply the DPC model, and as they are large and intended to be further processed, it is worthwhile to compress them losslessly.

4b.7 Application of reversible denoising and lifting steps to discrete wavelet transform

DWT employed in image compression algorithms decomposes an image into subbands of different characteristics that are independently entropy coded. Subbands represent image details of different orientations and sizes. For brevity, I describe here only the lifting-based reversible DWT with Cohen Daubechies Faveau (5,3) wavelet filter, reduced to essentials. Among others, it is exploited in baseline lossless JPEG 2000 compression of grayscale images. For further details as well as for more general characteristics of various variants of DWT and their application in JPEG 2000, the reader is referred to [21, 22, 29–32].

The one-dimensional DWT (1D-DWT) transforms in-place a discrete signal $S = s_0 s_1 s_2 \ldots s_{l-1}$ of finite length l into two subbands:

- a low-pass filtered signal L, that represents the low-frequency features of S;
- a high-pass filtered signal H containing high-frequency features that, along with the low-pass signal, allows the perfect reconstruction of the original signal.

S is transformed in 3 steps. First, in the prediction step, we perform the high-pass filtering of odd samples (hereafter, the parity of sample or pixel is determined by its location and not its value) by applying to each of them the following LS:

$$s_x \leftarrow s_x - \lfloor (s_{x-1} + s_{x+1})/2 \rfloor. \tag{8}$$

Another LS is then, during the update step, applied to each even sample:

$$s_x \leftarrow s_x + \lfloor (s_{x-1} + s_{x+1} + 2)/4 \rfloor. \tag{9}$$

Finally, in the reorder step, we reposition even samples to the lower half of the original signal, preserving their ordering (sample s_x is moved to $s_{x/2}$), and odd samples are moved to the upper half. We obtain separate subbands L and H, respectively.

The two-dimensional DWT (2D-DWT) of an image is obtained by first applying 1D-DWT to each image column, which results in L and H subbands of the image. Then, by applying 1D-DWT to each row, we obtain the 1-level DWT consisting of LL

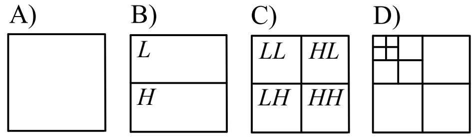

Figure 4: 1-level 2D-DWT (A–C) and 3-level 2D-DWT (D).

and HL subbands (transformed from L subband) and LH and HH subbands (from H subband). The 1-level DWT is presented in Fig. 4.A-C. The higher-level DWT, that provides multiresolution image representation, is obtained by Mallat decomposition [32]. The $t + 1$ transform is obtained by applying the 1-level transform to the LL subband of the t-level transform (Fig. 4.D).

LS employed in the prediction and update steps may result in propagating noise between subbands, i.e., noise originally contaminating a single sample is after DWT propagated to all the created subbands. Since subbands are encoded independently, noise propagation may worsen the compression effects, as the information on noise gets encoded several times. To limit the noise propagation, in [rs8] I proposed replacing of LS in the prediction (Eq. 8) and update (Eq. 9) steps by RDLS constructed based on them, i.e., by:

$$s_x \leftarrow s_x - \lfloor (s^d_{x-1} + s^d_{x+1})/2 \rfloor \text{ and} \tag{10}$$

$$s_x \leftarrow s_x + \lfloor (s^d_{x-1} + s^d_{x+1} + 2)/4 \rfloor, \tag{11}$$

respectively, where s^d_i denotes the denoised sample s_i.

A comparison of effects of DWT and DWT modified using RDLS (RDLS-DWT) for images contaminated with impulse noise or containing sharp lines is presented in Fig. 5; for denoising the median filter with 3×3 sample window was used.

For practical reasons (widely explained in [rs8]), in the example in Fig. 5, as well as in all the RDLS-DWT research done so far, for denoising of a given sample I used samples of the same parity only. As we can see in Fig. 5, a single noisy pixel results in the distortion of all subbands of the DWT transformed image. Furthermore, the noisy pixel's neighborhood, originally unaffected by noise, is now altered in all or most subbands, depending on the noisy pixel position in the original image. Sharp lines affect DWT similarly, resulting in altered line neighborhoods—due to the way 2D-DWT is built by using 1D-DWTs. For instance, the horizontal line in an image affects the 1D-DWT done for the image column the same way as the single impulse noise pixel. RDLS-DWT, due to the employed denoising, almost completely avoids the above-described problems.

In the publication [rs8] I reported results of application of RDLS-DWT in lossless JPEG 2000 compression of grayscale images. For non-photographic images, by employing a heuristic for an image-adaptive selection of nonlinear denoising filters, I obtained significant and useful from a practical standpoint improvements of compression ratio, on average by 14%. Non-photographic images are images which are different than the natural images; e.g., computer-generated, composed from others (including natural ones), or being screen shots. It is worth mentioning, that there currently is a growing interest in compression of this type of images, that are known as the screen content images; the most recent standard of video and image compression HEVC [33, 34] includes an extension for screen content image compression.

I continue the research on the methods for improving the efficiency of DWT-based image compression algorithms. In the research described in the previous paragraph

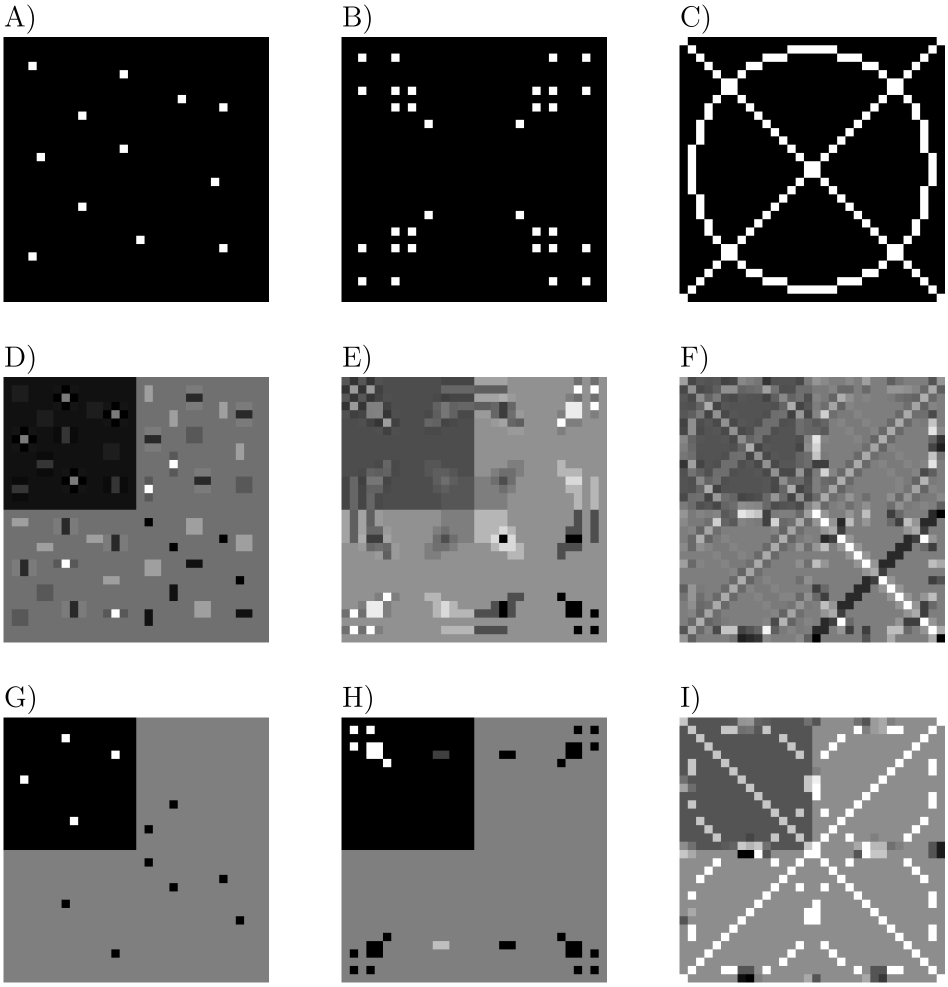

Figure 5: Effects of impulse noise and sharp lines on 1-level DWT and RDLS-DWT. (A–C) original images (32×32 pixels), (D–F) DWT transformed images, (G–I) RDLS-DWT transformed images. Transformed images are normalized to dynamic range of original ones.

I allowed the skipping of the entire RDLS-DWT stage—because RDLS-DWT (as well as DWT) worsens the obtained compression ratios for certain images. In the research on RDLS-modified color space transforms described in the previous Section, I also exploited the partial transform skipping, i.e., the skipping of selected transform steps. Selected steps were skipped by employing the denoising filter named in [rs7] the null; for the null filter $s_x^d = s_x$. In the case of RDLS-DWT, by using the null filter we may skip the prediction and update steps (as they are LS), but not the reorder step. My research done so far (described in the technical report [oth13] submitted to PLOS ONE, currently in review of the revised version /major revision/), showed, that by allowing to skip both LS and the reorder step, for the non-photographic images, we may get increased improvements of compression ratios attaining 17.5%. Interestingly, by using only the step skipping, compression ratio improvements close to the 14% improvement reported in [rs8] may be obtained at the cost of a negligible from a practical standpoint increase of the compression time and in compliance with the extended JPEG 2000 standard (using extensions from annexes F and H of the standard [29]). The compression ratio improvement by about 14% is obtained at the cost of increasing the compression time by 3% as compared to the unmodified JPEG 2000.

It is believed that the use of decorrelation that is not supported by an additional knowledge (e.g., knowledge on the presence of symmetry in medical images) does not lead to significant improvements of compression ratios of DWT subbands—which is confirmed by, e.g., Bruylants [31]. However, the characteristics of subbands obtained after RDLS-DWT is significantly different than in the case of DWT. I obtained very good preliminary research results of application of prediction to RDLS-DWT subbands (with the reorder step skipping allowed). I also obtained encouraging preliminary effects of applying the methods I proposed to the 3D-DWT employed by JPEG 2000 part 10 [35] in lossless compression of volumetric medical data.

The results described in this section were obtained by the use of methodology similar to the one used in the research on RDLS-modified color space transforms (described in [rs7]). I exploited similar RDLS filter selection heuristic and, except for the research reported in [rs8], similar entropy-based estimators of compression effects of the transformed data. The positive effects, obtained for significantly different transforms and data types, suggest that this methodology is in a certain degree general.

4b.8 List of the most important original achievements

I consider the following my original achievements to be the most important ones:

- proposing RDLS and developing a method for improving the efficiency of lifting-based reversible transforms by replacing LS with RDLS; the method results in transforms that are more general and better suited for different types of data and it connects domains that until now were separate: the lossless compression and the inherently lossy denoising; developing a methodology for the selection of denoising filters for RDLS;
- application of RDLS to reversible color space transforms and obtaining, for images in optical resolutions of acquisition devices, effects worthwhile from a practical standpoint;
- application of RDLS do DWT and obtaining, for non-photographic images, effects worthwhile from a practical standpoint;
- developing (as a result of the continuation of works started in the course of the doctoral dissertation) the simple, fast and adaptive lossless image compression

algorithm SFALIC that is well suited for compressing large images, high bit depth images, and noisy images; the prepared implementation is my most important original design, constructional and technological achievement; the algorithm is used in industry;

- noticing, that the method of constructing the reversible color space transforms based on transforms designed for lossy compression that in turn are based on an irreversible transform aimed at minimizing inter-component correlation is incorrect; proposing transforms designed differently and showing the effectiveness of such approach; obtaining a patent on application of one of the proposed transforms.

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5. Other scientific and research achievements.

a) Scientific achievements

Beside the works discussed within the series of related articles submitted as the habilitation achievement, my research activities concerned the following areas: (i) application of the DPC model in image denoising, (ii) methods exploited in the SFALIC algorithm, (iii) Application of HP in compression of various image types, and (iv) image retrieval in wavelet domain. The obtained results are briefly presented in the subsequent sections, and Section 5a.6 contains a list of selected works, that were published after obtaining the doctoral degree, but were not included into the series of related articles.

5a.1 Application of detector precision characteristics in image denoising

Application of the DPC model in the lossy compression was presented in Section 4b.5 and in the publication [rs4]. This model estimates the amount of noise in an image; naturally, such information may be used in image denoising. Cooperation on research on a denoising algorithm based on the DPC model was proposed to me by dr Bernaś. In the paper [oth1] we presented the proposed algorithm of denoising in wavelet domain based on the DPC model and we reported results of its evaluation. Efficiency of this algorithm depends on amount of noise in an image, yet it is better compared to other known denoising algorithms that were included in the comparison: AdaptShrink, BivarShrink i OraclShrink. I estimate that my contribution to this work is 25%; I was involved in design and evaluation of the proposed algorithm, analysis and interpretation of the obtained results, writing, and I was the corresponding author for this paper.

5a.2 Research on methods exploited in SFALIC algorithm

The research on the code family used by SFALIC, done in large part before completing the Ph.D., beside the already mentioned publication [rs1] was described in [oth2] and [oth3]. This research resulted in selecting the code family for SFALIC and influenced the data model of this algorithm. The RUF method exploited in SFALIC was also applied to the universal dictionary compressor LZW, which was described in [oth4]. As the result of the research I found, that the RUF method allows to increase the speed of the LZW algorithm by several dozens of percents at the cost of worsening the compression ratio by a few percents. Thus the method is useful from a practical standpoint, however, to a smaller extent than in the case of statistical image compression algorithm SFALIC.

5a.3 Applications of histogram packing in image compression

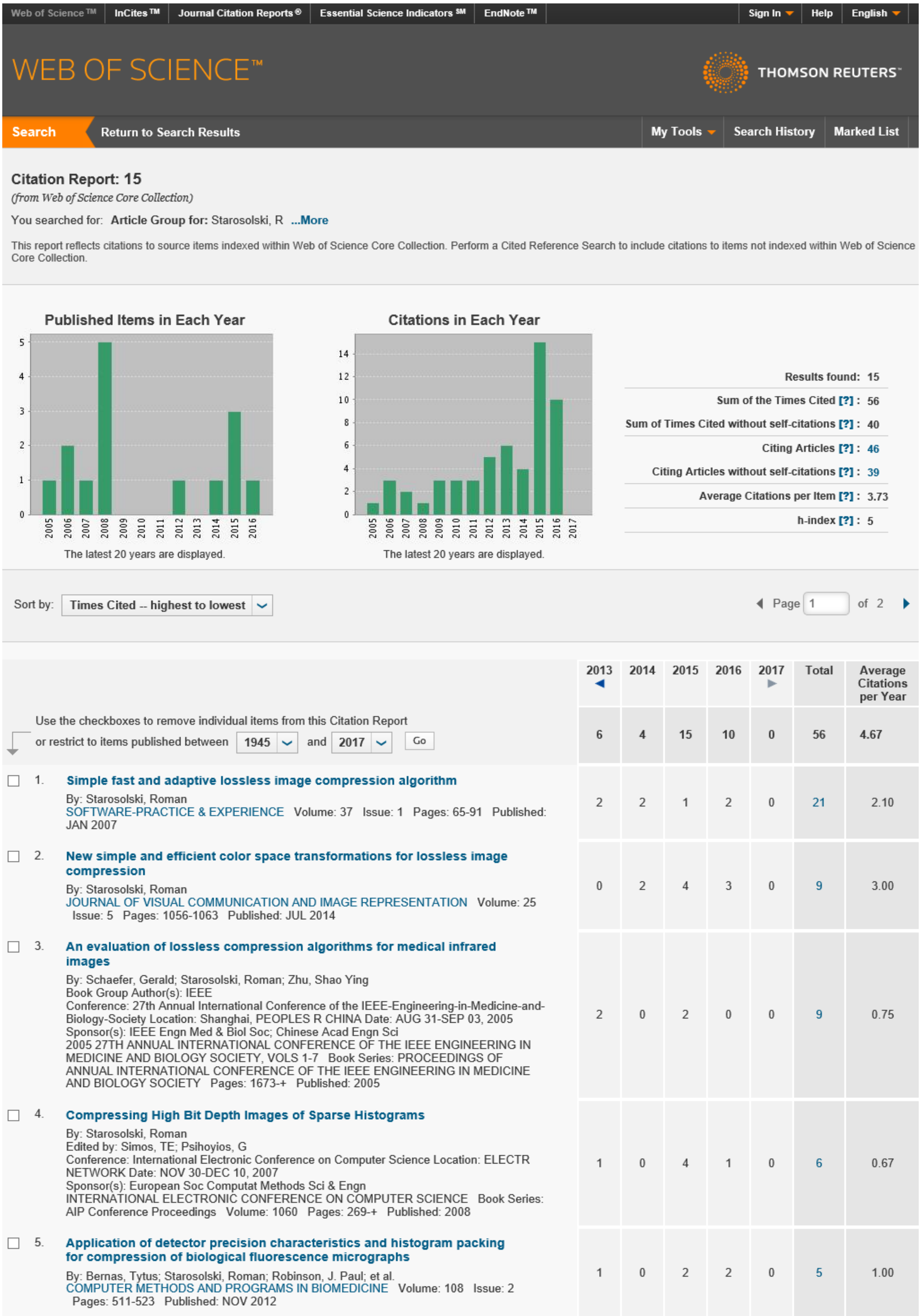
The effects of application of HP in lossy compression, presented in [rs4], are the most interesting research results obtained for the HP method, however, they are not the only results. A report on an earlier stage of research on application of HP to high bit depth images, that was then described in publication [rs3], was presented at the conference of the SPIE organization [oth5]; application of HP to medical and natural high bit depth images was also presented in an overview paper presented at the BDAS conference [oth6]. In cooperation with dr. Schaefer from Loughborough University I conducted research on exploiting HP in order to improve effects of compression of color medical retinal images and medical thermographs. In [oth7] we described the research on retinal images, wherein, in order to improve compression ratios we exploited HP and a color space transform. Significant compression ratio improvement due to HP, by about a dozen of percents, was observed for one of the four tested groups of images. Similar level of compression ratio improvement, but on average for all the tested images, was obtained for medical thermographs, that also are characterized by a certain level of histogram sparsity; the research was described in [oth8].

5a.4 Image retrieval in wavelet domain

I was also researching image retrieval from collections of compressed images employing algorithms operating in wavelet domain. Such algorithms allow to retrieve images without decompressing them—if the image is compressed using the transform algorithm exploiting DWT, e.g., an algorithm compliant to JPEG 2000. These works were conducted in cooperation with dr. Schaefer under the „Compressed domain retrieval of medical images" grant (WAR/342/44), which we obtained from the British Council. Research was done for medical thermographs. In the research, my two students, within the course of their Master of Science theses, implemented selected retrieval algorithms, as well as were involved in experiments and preparation of papers. These works are described in respective Master of Science theses and in [oth9], [oth10], and [oth11]. I did not continue these works, because they did not concern directly my primary area of research interests, i.e., compression.

5a.5 Summary

After completing my Ph.D., I was the sole author or co-author of 36 publications, out of which 8 were included into the series of related articles submitted as the habilitation achievement. Section 5a.6 contains a list of 16 publications, that were not included into the series. The list, beside the reviewed scientific publications cited in Section 5 of this summary of academic achievements, contains also two technical reports deposited permanently, freely and publicly in the arXiv preprint repository ([oth12] and [oth13]), two patent applications submitted to the Polish Patent Office and pending ([oth14] and [oth15]) and one granted patent [oth16]. These publications summarize the research that I conducted both independently and as part of various kinds of cooperation; among them were both the funded research and development projects (described in Section 5b) and projects carried out independently within the individual cooperation which I established with dr. Bernaś and dr. Schaefer. The total impact factor according to JCR of all my post-doctoral publications is about 7.0, 5-year impact factor—about 7.7, *h*-index – 5 (Fig. 6), whereas the total number of Ministry points is 317.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	6	4	15	10	0	56	4.67
1. **Simple fast and adaptive lossless image compression algorithm** By: Starosolski, Roman SOFTWARE-PRACTICE & EXPERIENCE Volume: 37 Issue: 1 Pages: 65-91 Published: JAN 2007	2	2	1	2	0	21	2.10
2. **New simple and efficient color space transformations for lossless image compression** By: Starosolski, Roman JOURNAL OF VISUAL COMMUNICATION AND IMAGE REPRESENTATION Volume: 25 Issue: 5 Pages: 1056-1063 Published: JUL 2014	0	2	4	3	0	9	3.00
3. **An evaluation of lossless compression algorithms for medical infrared images** By: Schaefer, Gerald; Starosolski, Roman; Zhu, Shao Ying Book Group Author(s): IEEE Conference: 27th Annual International Conference of the IEEE-Engineering-in-Medicine-and-Biology-Society Location: Shanghai, PEOPLES R CHINA Date: AUG 31-SEP 03, 2005 Sponsor(s): IEEE Engn Med & Biol Soc; Chinese Acad Engn Sci 2005 27TH ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY, VOLS 1-7 Book Series: PROCEEDINGS OF ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY Pages: 1673-+ Published: 2005	2	0	2	0	0	9	0.75
4. **Compressing High Bit Depth Images of Sparse Histograms** By: Starosolski, Roman Edited by: Simos, TE; Psihoyios, G Conference: International Electronic Conference on Computer Science Location: ELECTR NETWORK Date: NOV 30-DEC 10, 2007 Sponsor(s): European Soc Computat Methods Sci & Engn INTERNATIONAL ELECTRONIC CONFERENCE ON COMPUTER SCIENCE Book Series: AIP Conference Proceedings Volume: 1060 Pages: 269-+ Published: 2008	1	0	4	1	0	6	0.67
5. **Application of detector precision characteristics and histogram packing for compression of biological fluorescence micrographs** By: Bernas, Tytus; Starosolski, Roman; Robinson, J. Paul; et al. COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE Volume: 108 Issue: 2 Pages: 511-523 Published: NOV 2012	1	0	2	2	0	5	1.00

Figure 6: Web of Science Core Collection Citation Report, created on 25th November 2016.

5a.6 Selected publications not included in the series

[oth1] T. Bernas, R. Starosolski, and R. Wójcicki, "Application of detector precision characteristics for the denoising of biological micrographs in the wavelet domain," *Biomedical Signal Processing and Control*, vol. 19, pp. 1–13, doi 10.1016/j.bspc.2015.02.010, 2015. /IF=1.521, 5-year IF=1.588, 25 pts of Polish Ministry of Science and Higher Education/

[oth2] R. Starosolski, "Odwrócenie kolejności kodów w rodzinie Rice'a (Reversing the order of codes in the Rice family)," *Studia Informatica*, vol. 23(4), pp. 7–14, 2002. /1 pt of Polish Ministry of Science and Higher Education/

[oth3] R. Starosolski and W. Skarbek, "Modified Golomb-Rice Codes for Lossless Compression of Medical Images," in *Proc. International Conference on E-health in Common Europe (Cracow, 5-6 Jun. 2003)*, K. Zieliński and M. Duplaga (Eds.), pp. 423–437. Cyfronet, Poland, 2003.

[oth4] R. Starosolski, "Zastosowanie metody zmniejszonej częstości aktualizacji słownika w uniwersalnym algorytmie kompresji LZW (Application of the reduced dictionary updete frequency method to the LZW universal data compression algorithm)," *Studia Informatica*, vol. 31(3), pp. 5-22, 2010. /6 pts of Polish Ministry of Science and Higher Education/

[oth5] R. Starosolski, "Compressing images of sparse histograms," in *Proc. SPIE International Conference on Medical Imaging (Warsaw, 31 Oct - 01 Sept. 2005)*, A. Kowalczyk, A. F. Fercher, and V. V. Tuchin (Eds.), vol. 5959 of *Proceedings of SPIE*, pp. 209–217, doi 10.1117/12.624489. SPIE—The International Society for Optical Engineering, Bellingham, USA, 2005. /4 pts of Polish Ministry of Science and Higher Education/

[oth6] R. Starosolski, "Lossless Compression of Medical and Natural High Bit Depth Sparse Histogram Images," in *Beyond Databases, Architectures and Structures (11th International Conference BDAS 2015)*, S. Kozielski et al. (Eds.), vol. 521 of *Communications in Computer and Information Science*, pp. 363–376, doi 10.1007/978-3-319-18422-7_32. Springer, Switzerland, 2015. /Web of Science, 10 pts of Polish Ministry of Science and Higher Education/

[oth7] R. Starosolski and G. Schaefer, "Lossless compression of color medical retinal images," in *Proc. 20th European Conference on Modelling and Simulation (ECMS2006)*, W. Borutzky, A. Orsoni, and R. Zobel. (Eds.), pp. 437-444. Bonn, 2006. /3 pts of Polish Ministry of Science and Higher Education/

[oth8] R. Starosolski, G. Schaefer, and S. Y. Zhu, "Performance evaluation and optimisation of lossless image compression algorithms applied to medical infrared images," in *Proc. of 9th Medical Image Understanding and Analysis Conference (MIUA2005)*, pp. 47–50. British Machine Vision Association, Bristol, 2005. /3 pts of Polish Ministry of Science and Higher Education/

[oth9] G. Schaefer and R. Starosolski, "A comparison of two methods for retrieval of medical images in the compressed domain," in *Proc. of 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS2008)*, pp. 402–405, doi 10.1109/IEMBS.2008.4649175. IEEE, Piscataway, 2008. /Web of Science, 7 pts of Polish Ministry of Science and Higher Education/

[oth10] G. Schaefer, R. Starosolski, D. Pawlak, and S. Y. Zhu, "Wavelet based retrieval of medical thermograms," in *Proc. of 5th Int. Conference on Technology and Applications in Biomedicine (ITAB2008)*, pp. 135–137, doi

10.1109/ITAB.2008.4570596. IEEE, Piscataway, 2008. /Web of Science, 7 pts of Polish Ministry of Science and Higher Education/

[oth11] R. Starosolski, G. Schaefer, M. Molęda, and S. Y. Zhu, "Retrieval of medical images in wavelet compression domain," in *Proc. of 5th Int. Conference on Technology and Applications in Biomedicine (ITAB2008)*, pp. 157–159, doi 10.1109/ITAB.2008.4570597. IEEE, Piscataway, 2008. /Web of Science, 7 pts of Polish Ministry of Science and Higher Education/

[oth12] R. Starosolski, "Reversible denoising and lifting based color component transformation for lossless image compression," *arXiv:1508.06106 [cs.MM], http://arxiv.org/abs/1508.06106*, 2016.

[oth13] R. Starosolski, "Skipping Selected Steps of DWT Computation in Lossless JPEG 2000 for Improved Bitrates," *arXiv:1608.00613 [cs.MM], http://arxiv .org/abs/1608.00613*, 2016.

[oth14] R. Starosolski, "Sposób i system przetwarzania obrazu barwnego, zwłaszcza w urządzeniach akwizycji, przetwarzania i składowania lub transmisji obrazów przeprowadzających kompresję obrazów cyfrowych (Method and system of color image processing, especially in image acquisition, processing, and storage or transmission devices compressing digital images)," patent application nr. P.394125, filed on 2011.03.07, published on 2012.09.10, pending, Polish Patent Office, Warsaw. /Web of Science, 10 pts of Polish Ministry of Science and Higher Education/

[oth15] R. Starosolski, "Sposób przetwarzania obrazów barwnych i multispektralnych, a także danych wolumetrycznych, zwłaszcza w urządzeniach akwizycji, przetwarzania i składowania lub transmisji wykonujących kompresję danych zawierających znaczne ilości szumu (Method of color and multispectral image processing, as well as of volumetric data processing, especially in acquisition, processing, and storage or transmission devices compressing data containing significant amount of noise)," patent application nr. P.396766, filed on 2011.10.25, published on 2013.04.29, pending, Polish Patent Office, Warsaw. /Web of Science, 10 pts of Polish Ministry of Science and Higher Education/

[oth16] R. Starosolski, "Sposób i system przetwarzania obrazu barwnego w urządzeniach akwizycji, przetwarzania i składowania lub transmisji obrazów wykorzystujących kompresję obrazów cyfrowych (Method and system of color image processing in image acquisition, processing, and storage or transmission devices exploiting digital image compression)," patent granted on 2016.08.24 (application nr. P.393036, filed on 2010.11.24, published on 2012.06.04), Polish Patent Office, Warsaw. /Web of Science, 35 pts of Polish Ministry of Science and Higher Education/

b) Research and research-and-development projects

1. „Analiza możliwości zastosowania adaptacyjnych algorytmów statystycznych w szybkiej oraz bezstratnej kompresji obrazów medycznych oraz naturalnych obrazów w stopniach szarości (An analysis of fast and adaptive lossless image compression algorithms applied to medical and natural continuous tone images)", 2003–2005, grant KBN/MNiI (nr. 4T11C 032 24), role: manager.
2. „Virtual Electronic Poem", 2004–2005, grant within the EU Framework Programme Culture 2000, done by a consortium of: Virtual Reality and Multi Media Park (Italy), Technischen Universitaet of Berlin (Germany), University of Bath (Great Britain), and Silesian Technical University, role: manager of the team in Silesian Technical University and regional coordinator (contractor).

3. „Compressed domain retrieval of medical images", 2005–2007, grant of British Council and Polish Ministry of Science and Higher Education (nr. WAR/342/44), done by: Roman Starosolski (Institute of Informatics, Silesian Technical University) and Gerald Schaefer (School of Engineering and Applied Science, Aston University, Birmingham).
4. Individual statutory research projects (BW) of the Institute of Informatics, Silesian Technical University, 2002-2004, role: manager.
5. General statutory Research Projects (BK) of the Institute of Informatics, Silesian Technical University, 2002 and 2005-2016, member of the research team led by prof. dr hab. inż. Zbigniew J. Czech.
6. Rector's Habilitation Grant nr. 02/020/RGH15/0060, 2015–2016, granted by the Rector of the Silesian University of Technology.

c) Additional information

Since 2014 I reviewed 17 manuscripts (some of them several times) submitted to JCR journals:

i) IEEE Transactions on Image Processing /IF: 3.735, 5-year IF: 4.786/

ii) Expert Systems With Applications /IF: 2.981, 5-year IF: 2.879/

iii) SPIE Journal of Biomedical Optics /IF: 2.556, 5-year IF: 2.603/

iv) IEEE Transactions on Circuits and Systems for Video Technology /IF: 2.254, 5-year IF: 2.617/

v) IEEE Signal Processing Letters /IF: 1.661, 5-year IF: 1.852/

vi) IET Image Processing /IF: 0.860, 5-year IF: 1.048/

vii) Color Research and Application /IF: 0.847, 5-year IF: 1.173/

viii) Journal of Electronic Imaging (SPIE) /IF: 0.616, 5-year IF: 0.840/

ix) Journal of Imaging Science and Technology /IF: 0.316, 5-year IF: 0.397/

I prepared the curriculum for modules I taught, among others, at Computer Science Faculty and Macrofaculty (in English), I led the lectures for Ph.D. students. Moreover, I supervised about 40 Master of Science theses and 10 Engineer theses.