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FACULTY OF COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME II

- Session 6 - Environmental Systems: Management and Optimisation
- Session 7 - New Methods and Technologies for Medicine and Biology
- Session 8 - Embedded System Design and Application
- Session 9 - Image Processing, Image Analysis and Computer Vision
- Session 10 - Mobile Communications
- Session 11 - Education in Computer Science and Automation

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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52^{nd} Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
10 – 13 September 2007

A. Mitsiukhin /V. Pachynin/ E. Petrovskaya

Hartley Discrete Transform Image Coding

IMAGE PROCESSING, IMAGE ANALYSIS AND COMPUTER VISION

The prevailing development vector in modern radio-electronic information-measuring systems (complexes) is the introduction of digital methods and processing, transformations and signaling. However the use of digital methods leads to an increase in a frequency bandwidth, reduction of the processing rate and the volume of transferred data. Traditional problems for digital systems are their speed and utilized algorithms. In part these problems can be resolved by the development of effective digital coding methods (compression) of information.

Information compression methods eliminate the redundancy of digital representation of the information. They represent a procedure of linear digital signal coding on the basis of discrete unitary transforms (discrete Fourier (DFT), Walsh-Hadamard (WHT), Haar, cosine (DCT), etc.).

This paper addresses the compression of video information (images) that is to be transmitted using two-dimensional digital signals, using the Hartley discrete orthogonal transform (DHT). The compression efficiency is estimated and compared with the presently used DCT and WHT.

In general the transformation coding is realized in two operations. The first operation is the linear transformation of the original data. The second operation reduces (selects) the transformation factors (transformants). The number of these transformants can be reduced by fixing some threshold level of values or by allocating the most informative zones in a floor of spatial frequencies of digital images. Below we describe the procedures of zone selection (filtration) of transformation factors with the use of DHT.

The procedure of an efficient coding of two-dimensional digital signals is as follows:

1. A direct two-dimensional DHT of the original NxN image fragment is calculated. It can be represented the matrix form as

$$\left[G(k_1,k_2)\right]=\frac{1}{N}\left[\nu(k,n)\right]\left[g(n_1,n_2)\right]\left[\nu(k,n)\right]^T, k_1,k_2,n_1,n_2 \in \{0,1,\dots N-1\}, \tag{1}$$

where $\left[g(n_1,n_2)\right]$ is the readout matrix of the image of size NxN; $\left[G(k_1,k_2)\right]$ - the NxN matrix of DHT factors; $[\nu(k,n)]$- an NxN kernel of the DHT transform;

$\left[\nu(k,n)\right]=\left[cas\,\frac{2\pi kn}{N}\right],\ k,n \in \{0,1,\dots N-1\}$

$$\text{where}\quad cas\left(\frac{2\pi kn}{N}\right)=\cos\left(\frac{2\pi kn}{N}\right)+\sin\left(\frac{2\pi kn}{N}\right). \tag{2}$$

The 2D reverse Hartley transform has the form of

$$\left[g(n_1,n_2)\right]=\frac{1}{N}\left[\nu(k,n)\right]^T\left[G(k_1,k_2)\right]\left[\nu(k,n)\right]. \tag{3}$$

Transformation matrices of the direct and reverse DHT are identical, as $\left[\nu(k,n)\right]=\left[\nu(k,n)\right]^T$.

2. Zone filtration of transformant is being performed, which requires prior knowledge of the distribution function for a two-dimensional dispersion of transformation factors

$$diag[\sigma^2]=diag\left[\widetilde{K}_C\right]\otimes diag\left[\widetilde{K}_R\right], \tag{4}$$

where $\otimes$ is the Kronecker product of matrices; $diag\left[\widetilde{K}_C\right]$и $diag\left[\widetilde{K}_R\right]$ - diagonal covariances matrices of transformation factors columns and rows respectively. Covariance matrices K_C and K_R in the field of originals and in the area of images are connected by transformation of similarity. Then $\left[\widetilde{K}_C\right]$ и $\left[\widetilde{K}_R\right]$ are defined from expressions

$$\left[\widetilde{K}_C\right]=\left[\nu(k,n)\right]\left[K_C\right]\left[\nu(k,n)\right]^T, \tag{5}$$

$$\left[\widetilde{K}_R\right]=\left[\nu(k,n)\right]\left[K_R\right]\left[\nu(k,n)\right]^T. \tag{6}$$

After lexicographic transformation of a matrix $diag[\sigma^2]$ the matrix [L], is formed, which defines the zone of transformant selection. Recovery of the original image fragments is performed by the reverse spectral transformation according to the dispersive criterion, where the kept transformants possess the greatest dispersions chosen by the filtration zone. The following example shows the estimation of quality of 8x8 fragment compression for the three transformations: DCT, DWAT, and investigated DHT.

Example. An input image fragment has the size of 8x8. The image is described by the Toeplitza distribution. The correlation factor *p* for adjacent readouts is set to 0.9.

The covariance matrix for the fragment's columns and rows and the DHT kernel (2) is as follows:

$$K_C = K_R = \begin{pmatrix} 1 & 0.9 & 0.81 & 0.729 & 0.656 & 0.59 & 0.531 & 0.478 \\ 0.9 & 1 & 0.9 & 0.81 & 0.729 & 0.656 & 0.59 & 0.531 \\ 0.81 & 0.9 & 1 & 0.9 & 0.81 & 0.729 & 0.656 & 0.59 \\ 0.729 & 0.81 & 0.9 & 1 & 0.9 & 0.81 & 0.729 & 0.656 \\ 0.656 & 0.729 & 0.81 & 0.9 & 1 & 0.9' & 0.81 & 0.729 \\ 0.59 & 0.656 & 0.729 & 0.81 & 0.9 & 1 & 0.9 & 0.81 \\ 0.531 & 0.59 & 0.656 & 0.729 & 0.81 & 0.9 & 1 & 0.9 \\ 0.478 & 0.531 & 0.59 & 0.656 & 0.729 & 0.81 & 0.9 & 1 \end{pmatrix} .$$

$$\nu(k,n) := \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1.414 & 1 & 0 & -1 & -1.414 & -1 & 0 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 0 & -1 & 1.414 & -1 & 0 & 1 & -1.414 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1.414 & 1 & 0 & -1 & 1.414 & -1 & 0 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 0 & -1 & -1.414 & -1 & 0 & 1 & 1.414 \end{pmatrix}$$

The covariance matrix in the area of images for columns and rows (5), (6) is equal to:

$$\widetilde{K}_C = \widetilde{K}_R = \begin{pmatrix} 49.478 & -0.956 & 0 & 0.069 & 0 & -0.166 & -0.566 & -2.307 \\ -0.956 & 6.03 & 1.907 & 1.351 & 0.956 & 0.558 & -4.414\times 10^{-3} & -1.351 \\ 0 & 1.907 & 1.97 & 0.8 & 0.566 & 0.331 & 0 & -0.79 \\ 0.069 & 1.351 & 0.8 & 1.06 & 0.402 & 0.235 & 6.56\times 10^{-4} & -0.558 \\ 0 & 0.956 & 0.566 & 0.402 & 0.706 & 0.166 & 0 & -0.396 \\ -0.166 & 0.558 & 0.331 & 0.235 & 0.166 & 0.589 & -1.586\times 10^{-3} & -0.235 \\ -0.566 & -4.414\times 10^{-3} & 0 & 6.56\times 10^{-4} & 0 & -1.586\times 10^{-3} & 0.838 & -0.011 \\ -2.307 & -1.351 & -0.79 & -0.558 & -0.396 & -0.235 & -0.011 & 3.328 \end{pmatrix} .$$

The diagonal covariance matrix for columns and rows is

$$diag[\widetilde{K}_C] = diag[\widetilde{K}_R] = \begin{pmatrix} 49.478 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 6.03 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.97 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.06 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.706 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.589 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.838 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.328 \end{pmatrix} .$$

From formula (4), a matrix of values can be obtained:

$$diag(\sigma^2) = \begin{bmatrix} 38.254 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 4.663 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.522 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.816 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.544 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.458 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.649 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.573 & 0 & 0 & 0 \\ * & * & * & * & * & * & * & * & * & * & * \\ * & * & * & * & * & * & * & * & * & * & * \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.031 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.044 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.173 \end{bmatrix}$$

After the lexicographic transform of the matrix $diag(\sigma^2)$ the matrix [L] is formed as:

$$L := \begin{pmatrix} 2448 & 298.352 & 97.472 & 52.447 & 34.931 & 29.143 & 41.463 & 164.663 \\ 298.352 & 36.361 & 11.879 & 6.392 & 4.257 & 3.552 & 5.053 & 20.068 \\ 97.472 & 11.879 & 3.881 & 2.088 & 1.391 & 1.16 & 1.651 & 6.556 \\ 52.447 & 6.392 & 2.088 & 1.124 & 0.748 & 0.624 & 0.888 & 3.528 \\ 34.931 & 4.257 & 1.391 & 0.748 & 0.498 & 0.416 & 0.592 & 2.35 \\ 29.143 & 3.552 & 1.16 & 0.624 & 0.416 & 0.347 & 0.494 & 1.96 \\ 41.463 & 5.053 & 1.651 & 0.888 & 0.592 & 0.494 & 0.702 & 2.789 \\ 164.663 & 20.068 & 6.556 & 3.528 & 2.35 & 1.96 & 2.789 & 11.076 \end{pmatrix}.$$

From the matrix L it is possible to define the zone of the transformant filtration. For example, for the compression factor of 1.3 the zone has the following shape (the highlighted part of a matrix):

L=

2448	298.352	97.472	52.447	34.931	29.143	41.463	164.663
298.352	36.361	11.879	6.392	4.257	3.552	5.053	20.068
97.472	11.879	3.881	2.088	1.391	1.16	1.651	6.556
52.447	6.392	2.088	1.124	0.748	0.624	0.888	3.528
34.931	4.257	1.391	0.748	0.498	0.416	0.592	2.35
29.143	3.552	1.16	0.624	0.416	0.347	0.494	1.96
41.463	5.053	1.651	0.888	0.592	0.494	0.702	2.789
164.663	20.068	6.556	3.528	2.35	1.96	2.789	11.076

Distortions, resulting from the compression procedure, can be estimated by the mean-square error (MSE) of one signal readout, defined using the formula:

$$\sigma^2 = \frac{1}{64}\left[\sum_{i=0}^{7}\sum_{j=0}^{7}\sigma_{i,j}\right] ,$$

where i, j belong to the chosen zone of filtration. The coding efficiency estimate using a dispersive criterion is illustrated in Figure 1 and 2.

Table 1. Mean-square error of DCT, DHT and DWAT transforms

к	1.1	1.3	1.63	2	4
DCT	0,0003422	0,001208	0,003208	0,005973	0,035
DHT	0,0006529	0,002231	0,006028	0,011	0,043
DWAT	0,0008346	0,002354	0,006042	0,009432	0,04

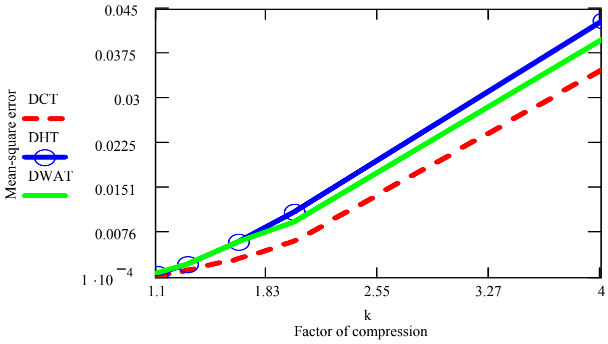

Fig. 1: MSE as a function of on compression factors with the correlation factor p = 0.9, image size of fragments is 8x8.

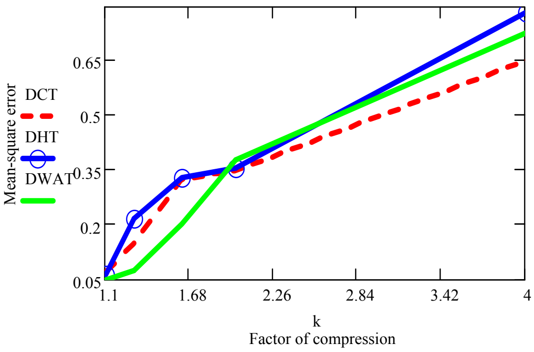

Fig. 2: MSE as a function of compression coefficient for a real fragment of the size of 8x8

Conclusion: Computing complexity of the fast DHT algorithm is lower than that of the fast DCT algorithm. Therefore, DHT compression might prove to be valuable for practical purposes.

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