Number 5, Volume VI, December 2011

THE QUALITY COMPARSION OF SVD AND DCT BASED IMAGE COMPERSSION METHODS FOR EMBEDDED DEVICES

Martin Dobrovolný[1]

Summary: This article presents results of the SVD based asymmetric image compression method for static image data in comparison to conventional compression methods based on DCT. The described method has been developed as an additional method for transferring static images transfer to personal video portable units from a central control system.

Key words: Lossy image compression, SVD, DCT, Image processing, Embedded devices

INTRODUCTION

In many applications requirements on asymmetric data often demand on one-way transmission of large amount of image data. In the article Asymmetric Image Compression for Embedded Devices based on Singular Value Decomposition (*SVD*) the asymmetric compression algorithm for the low-cost portable personal units is described. These systems using cheap portable personal units in distributed solutions are often focused mainly on the transmission of voice and data at low bit rates (measured data, location data…). This condition is given by the transmission technology (eg *GPRS*), and by the possibilities of the processors used in embedded devices. In some special cases there exist requirements on one-way transmission of image data. For these situations a special algorithm of image compression based on Singular Value Decomposition (*SVD*) was developed with dynamic selection of number of suppressed coefficients depending on the current channel bandwidth (1).

Prior to the implementation the developed algorithm was tested in terms of a reconstruction time and of its impact on the quality of the reconstructed image matrix. The obtained results were compared in detail with standard solutions (e.g. with algorithms based on *DCT*).

1. TRANSMISSION OF IMAGE DATA TO THE PERSONAL UNITS

Systems using cheap portable personal units in distributed solutions (data collection, communication between members of the rescue team), are often focused on voice and data communication at low bit rates (measured data, location data, and output sensors). If there is a requirement to include some technology of static images transfer, methods based on discrete Cosine transform (*DCT*) are commonly chosen. Compression algorithms based on *DCT*

[1] Ing Martin Dobrovolný, Ph.D., University of Pardubice, Faculty of Electrical Engineering and Informatics, Department of Electrical Engineering, Studentská 95, 53210 Pardubice, Tel.: +420 466 036 495, E-mail: martin.dobrovolny@upce.cz

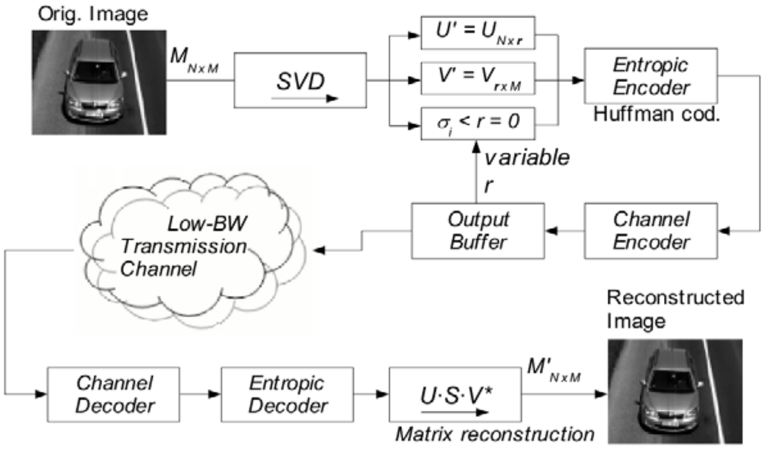
typically used in this situation lead to easily predictable results. The main disadvantage of this way is a low speed image decompression in cases of slow processors application at the receiver side. The unacceptable degradation of images is the further deficiency of this method when high compression ratio is needed in a low bit rate transmission channel.

Recently the alternative compression algorithms based on the use of Wavelet transforms has been applied, often in its simplest form using Haar transform and hierarchical decomposition (2), (3). The disadvantage of these procedures is a significant complexity of the entropic coders (*EBCOT*) and high computational demands of the decompression algorithms (2D signal filtering) (4) (5). Therefore, these methods are far less widespread comparing to the proven *DCT* and Huffman entropy encoder.

In the article (1) we described an alternative solution to these image compression methods based on image matrix singular value decomposition (SVD). Using *SVD* it is possible to achieve significant compression ratios. The approximation error is evenly distributed across the image identically to the wavelet transform and in terms of a subjective quality assessment even the impact of a high compression ratio is acceptable (6).

Another benefit of the compression methods based on *SVD* is an eligible algorithmic complexity. The asymmetrical distribution of encoder and decoder computing requirements could also be a big advantage in some cases. The image encoder is usually implemented on a powerful central site, while the portable personal units implement only simple matrix operations for image reconstruction, without great demands on computing power. Mainly for these reasons the compression based on singular decomposition of image matrix was choosen for the personal portable units.

The described method has been developed as an additional method for static images transfer to the personal video portable units from the central control system (1). Portable units are characterized by a low computational power. Therefore, in the development particularly the low algorithmic complexity of the decoder was emphasized. Wireless transmission is realized through low bandwidth auxiliary channels. In the proposed system images in a preview quality with a resolution of about 256^2 pixels are transmitted by an auxiliary data channel with a bandwidth around 10 kbps to 100 kbps, using the compression based on the singular decomposition of the image matrix. Number of suppressed eigenvalues at the encoder side is given by the current channel bandwidth - parameter *r*.



Source: Author

Fig. 1 - Architecture of a static image transmission chain (1)

The Figure 1 presents architecture of the transmission system. Very important is the feedback which indicates the fullness of the output buffer. By the feedback the current utilization of the transmission channel is detected allowing for a dynamic selection of suppressed coefficients σ_i which determines the quality of the image matrix Ω approximation. The target solution will include an entropic Huffman coder to encode the coefficients of U, V and $\Sigma^{1/2}$ matrices (later on), and a channel encoder for data security provision. The Huffman encoder was chosen because of its low demand on a memory space (at the decoder side) in contrast to the more efficient dictionary methods.

2. METHOD DESCRIPTION

A more detailed description of the method was introduced in (1). The principle of the method is finding of a suitable decomposition of the original image matrix Ω of the original image with N x M optical elements using the appropriate transformation matrices U and V and the diagonal matrix $\Sigma^{1/2}$.

Transformation of a real matrix can be done by decomposition to a product:

$$\Omega = U\sum^{1/2}V^T \tag{1}$$

where U and V are orthogonal matrices of size N x k and $\Sigma^{1/2}$ is a diagonal matrix of size k x k.

The equation (1) shows that the original image signal Ω can be expressed in terms of singular decomposition of matrices forming the appropriate base spaces, and the diagonal matrix $\Sigma^{1/2}$ is a link between these spaces (eigenvalues Ω) (7), (8).

So we are looking for the decomposition of the original signal in the form:

$$\Omega = (u_1 \ldots u_r \ldots u_m)\begin{pmatrix} \sigma_1 & & & & \\ & \ddots & & & \\ & & \sigma_i & & \\ & & & \ddots & \\ & & & & \sigma_k \end{pmatrix}\begin{pmatrix} v_1^T \\ \vdots \\ v_i^T \\ \vdots \\ v_k^T \end{pmatrix} \tag{2}$$

where the matrix *U* contains the first set of eigenvectors of Ω and the matrix *V* contains the second one.

Matrix $\Sigma^{1/2}$ is diagonal. The eigenvalues may be appropriately rearranged (sorted):

$$\sigma_1 \geq \sigma_2 \geq \ldots\sigma_i \geq \sigma_{i+1} = \ldots = \sigma_\lambda = 0 \quad (3)$$

where λ is the rank of the matrix Ω. Also the columns of the matrix *U* and rows of the matrix V^T must be rearranged accordingly.

The choice of the number of non-zero eigenvalues in the diagonal matrix $\Sigma^{1/2}$ is **the key to the (lossy) compression of the image signal**.

If $rank(\Sigma^{1/2}) \leq N$, it is possible to exclude from the base space vectors with zero valued characteristic numbers, that are not represented in the signal and not to transfer them.

If we sort the diagonal elements of the matrix $\Sigma^{1/2}$ from the largest eigenvalue σ_1^{max} to the smallest σ_p^{min}, it is possible to omit the sub-matrices corresponding to eigenvalues equal to zero from the σ_{p+1} to the σ_N in transmission, without any qualitative impact on the transmitted signal (lossless compression).

Since the absolute values of eigenvalues $|\sigma_i|$ of the diagonal matrix $\Sigma^{1/2}$ represent the contribution of eigenvectors υ_i to the overall expression of the signal energy $E|\Omega|$, it is possible to achieve a lossy compression by suppression of small coefficients.

In this case the threshold value *R* is and the eigenvalues of $|\sigma_i| < R$ are dropped. However, in this case the original signal Ω cannot be represented accurately.

Due to the suppression of the coefficients of $|\sigma_i| < R$ the corresponding columns of matrices *U* and *V* may be omitted too.

The computational complexity of the lossy described is highly asymmetric in nature. This is advantageous in terms of implementation of the decompression to the portable personal units with a low computation power. The signal reconstruction is carried out by (1).

3. TESTING PROCESS

Suppression of the selected coefficients σ_i leads to irreversible degradation of the images. By using the Matlab-model the impact of changes in the suppression of the diagonal matrix coefficients of input images was simulated and the necessary computing times required for reconstruction of the image matrix was evaluated. The test was realized on a base image set consisting of approximately two hundred images. For a more objective comparison of the test results the images with typical traffic situations was processed.

The proposed algorithm was compared with the traditional technique based on the *DCT*[2] compression for every image with the same quality for the every image. The Mean Square Error (*MSE*) between the original and the reconstructed matrices criterion was adopted for an objective determination of the reconstructed images quality. Due to the target platform constrains the time of image matrix reconstruction is a crucial parameter.

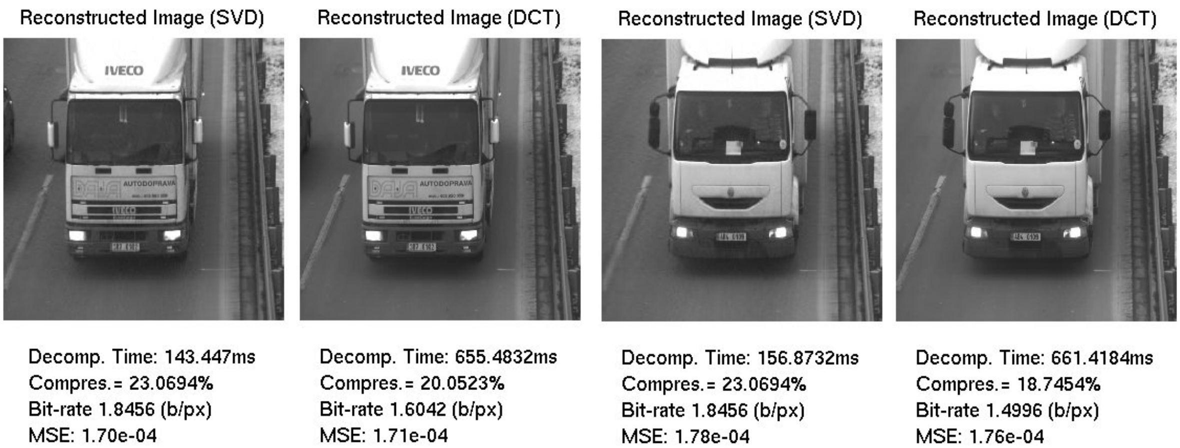
---

[2] For the DCT were selected blocks of size 8x8 pixels and the default quantization matrix according to ISO standard 10918-X: 1994

3.1 Test Results

The testing of the compression and reconstruction times was realized with a group of selected images at several levels. Since the entropic encoder is lossless and therefore has no impact on the resulting image quality it was not included in the total processing time.

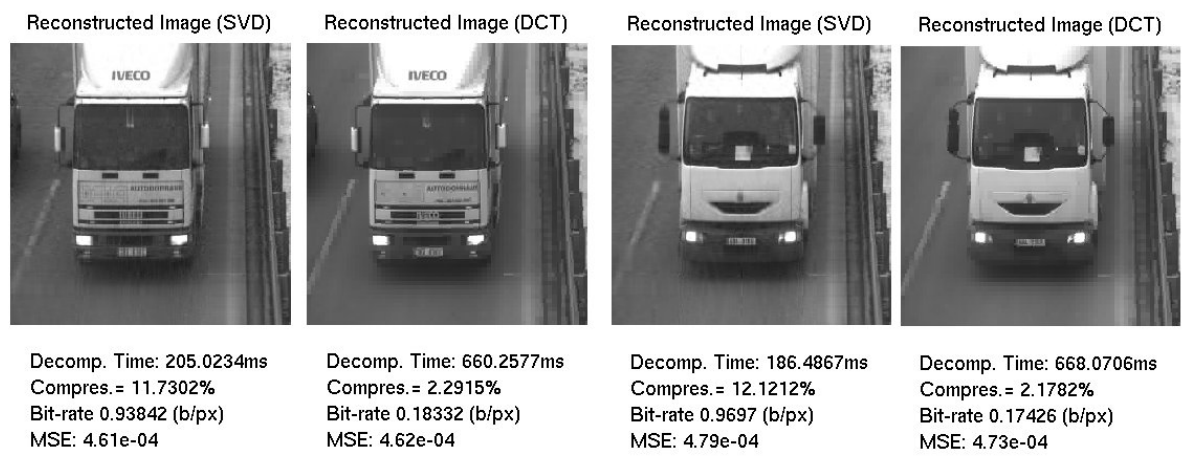
The first series of tests was performed with the reconstructed images of a high image quality. The main criterion in this case was to obtain the reconstructed matrix with *MSE* less than or equal to about 2×10^{-4} because in this case the achieved compression ratio in terms of calculation time is completely satisfactory and the image matrix degradation is minimal. An example of such a result is shown in the Figure 2. The *DCT* based compression at the same quality of reconstructed matrix Ω, achieves insignificantly higher compression level, but at the cost of more than 4.5 times greater calculation time (for the same resolution), which is the crucial parameter for us.



Source: Author

Fig. 2 - Comparison of computation time and compression for high-image quality with the same *MSE*

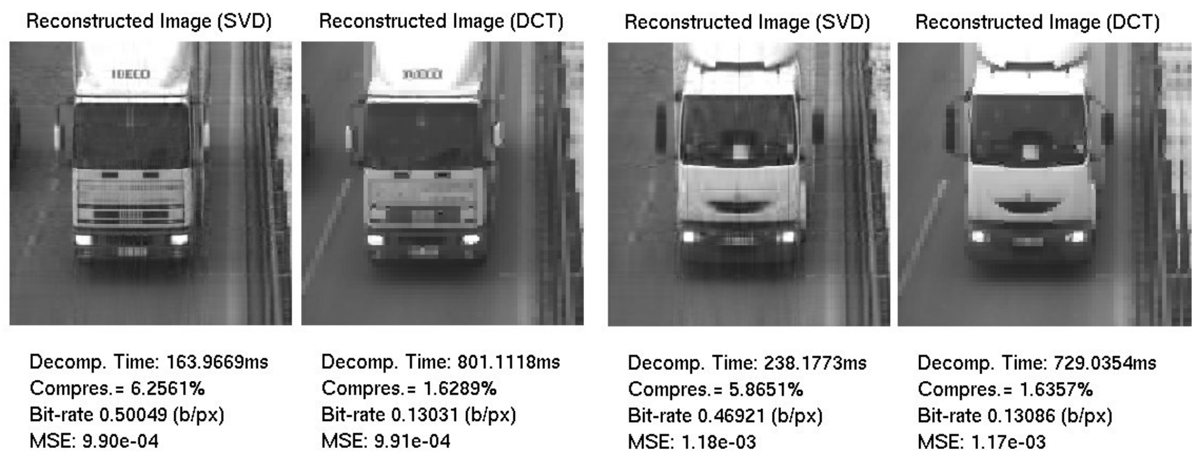
Due to the visualization capabilities of the target platform the limit level of the reconstructed matrix quality (represented by *MSE*) was established to the level about □ 5×10^{-4} (1). In this case additional increase of the compression ratio of SVD compression (Figure 3) leads to the rapid growth of the differential error (expressed by *MSE*). However the calculation time is roughly constant. The error in the reconstructed image is evenly distributed throughout the image area (like in the Wavelet Transform) and it is acceptable regarding to the projection on the target platform.



Source: Author

Fig. 3 - The comparison of compression results for the limit acceptable compression ratio of matrix Ω (for the same *MSE*)

During the test the worst cases were also tested. In cases where the inappropriate compression ratio was chosen it leaded to an unacceptable degradation of the image (Figure 4). This condition must be limited and controlled in the target application by selecting the limit value of the parameter *R*. But even in this extreme case the degradation caused by *SVD* compression was subjectively better considered.



Source: Author

Figure 4 – An unacceptable degradation of the reconstructed image resulting from the suppression of an excessive number of the coefficients (for the same *MSE*)

As mentioned in (1), the efficiency of the matrix decomposition for image compression increases with the processed data amount. A greater resolution of the input image leads to a better approximation of the input matrix resulting in a higher number of suppressed coefficients and thus in a higher compression level. This scenario has not been tested yet.

4. CONCLUSION

The realized tests on the proposed system of the lossy image compression confirmed the good signal reconstruction time while maintaining acceptable image degradation. One benefit of the method is the constant calculation time, in the case of increasing the compression ratio. The comparison to the *DCT* well illustrates the possibility to transfer the images using a very low bandwidth transmission channel. Commonly used solutions, as *DCT* or *WT*, are unsuitable for their excessive algorithmic complexity, or due to an unacceptable computation time. While maintaining the same quality of images the presented method is faster than the *DCT* and its approximation error is similarly to the *WT* evenly distributed across the image being acceptable regarding to the projection on the target platform. In the proposed method it is necessary to underscore the highly efficient video encoder and the fast reconstruction of the original image matrix.

5. ACKNOWLEDGMENT

The results presented in this paper were supported by the project DIGIREP of the Czech Ministry of Industry and Trade No. FR-TI3/297.

REFERENCES

(1) DOBROVOLNÝ M. ŠILAR Z., ČERNÝ M. *Asymmetric Image Compression for Embedded Devices based on Singular Value Decomposition*, IEEE Applied Electronics Pilsen, 2011.

(2) BHARDWAJ A., ALI R. *Image Compression Using Modified Fast Haar Wavelet Transform*, World Applied Sciences Journal 7 (5): 647-653, 2009 , ISSN 1818-4952.

(3) MORTON P., GlLINDEN K. *Image Compression Using the Haar wavelet transform*, Plenum Press 1996.

(4) VARMA, K., DAMECHARLA A., CARLETTA H. *A Fast JPEG2000 EBCOT Tier-1 Architecture That Preserves Coding Efficiency*, IEEE International Conference on Im. Process. 2006, ISSN: 1522-4880.

(5) SARAWADEKAR, K. BANERJEE, S. *Area efficient, high-speed VLSI design for EBCOT block coder in JPEG 2000*, Electronics and Information Engineering (ICEIE), 2010 International Conference, Kyoto 2010, ISBN: 978-1-4244-7679-4.

(6) SINGH, S.K., KUMAR, S. *A Framework to Design Novel SVD Based Color Image Compression*, Computer Modeling and Simulation, 2009. EMS '09. Third UKSim European Symposium, Athens 2010, ISBN: 978-1-4244-5345-0.

(7) CASTELMAN K. R. *Digital Image Processing, Prentice-Hall, New Jersey*, USA 1996.

(8) FORSYTH D., PONCE J. *Computer Vision: A Modern Approach*, ISBN: 0130851981.

(9) PETROU M, BOSDOGIANNI P *Image Processing: The Fundamentals*, Wiley; 1 edition (October 5, 1999), ISBN: 0471998834.