Georgian Scientists
ქართველი მეცნიერები
Vol. 7 Issue 1, 2025
https://doi.org/10.52340/gs.2025.07.01.44

Various aspects of image encoding based on linear transformations

Lali Khuntsaria

Professor, Department of production innovations and operations Management, Georgian Technical University, Georgia, 0160, Tbilisi, M. Kostava 77, E-mail: lalikhuntsaria02@gmail.com

Abstract:

The modern world is developing in the era of the fourth industrial revolution, which creates a global economy. It assumes the integration of updated, intelligent technologies with production, complete automation of work processes, machine learning, the use of artificial intelligence in almost all areas, consideration of cybersecurity issues, and many others. In accordance with the above processes, the dynamic development of the information and telecommunications sector, scientific innovations and their practical value remain a topical issue. One such task is research into the efficient processing, storage, and transmission of digital audio @ video signals.

Key words: Linear transformations, elementary and group-based (block, fragment) methods, JPEG and MPEG standards for dynamic image compression.

Main task:

The problem of efficient encoding of digital image signals from various classes and standards, with varying levels of compression and quality in the reconstructed images, can be addressed using both elementary and group-based (block, fragment) methods. These include differential pulse-code modulation; vector quantization; fractal coding; wavelet transform utilizing Haar functions; coding based on pyramidal structures; morphological coding and coding using various linear transformations; coding with motion estimation and compensation, and others. The encoding method based on linear transformations of images belongs to group methods, in the case of which one-dimensional, two-dimensional (intra-frame encoding) or three-dimensional (inter-frame encoding) fragments composed of n elements of the initial image are processed. High efficiency of K coding can be achieved by using so-called composite or hybrid methods, when two or more methods are combined.

The JPEG and MPEG standards for dynamic image compression, as recommended by the International Organization for Standardization, integrate a combination of discrete cosine transform, motion

prediction, and entropy coding techniques. Therefore, among the above-mentioned coding methods, the method using linear transformations occupies a prominent place due to its high efficiency.

Due to the problem of economical use of the bandwidth of digital telecommunication channels and the volume of devices storing the corresponding signals, the compact representation of digital signals is one of the current tasks. It is particularly problematic for high-information image signals, which is why they are distinguished from other types of signals by their broadband nature. It is known from the literature that if the bandwidth of a telecommunication channel is DF, then a digital signal represented in the form of two-level pulses (bits or binary symbols) can be transmitted over a telecommunication channel with a bandwidth of DF at a rate of 2DF bits/s, which means that in this case the efficiency of using the channel frequency band and, consequently, the bandwidth is 2 (bits/s) Hz. For example, the digital signal speed corresponding to high-definition television broadcasting (the number of lines in a frame is 1125, and the frame format is 16:9), which is currently widely developed in the USA, reaches 450 Mbit/s when the frames are scattered at a frequency of 25 Hz, which is why the bandwidth of the corresponding channel should not be less than 225 MHz. It is clear that both the standard terrestrial television broadcasting channel, which has a bandwidth of 8 MHz, and the satellite channel with a bandwidth of 27 MHz are unsuitable for transmitting such a signal. In order to enable the transmission of a high-definition digital television signal, in the first case, the transmission speed must be reduced by almost 29 times (29-fold compression), and in the second case, by almost 9 times (9-fold compression). This problem will become more relevant in the future, when it will be necessary to transmit stereo and multi-angle television digital signals over telecommunication channels and create archives of the corresponding images.

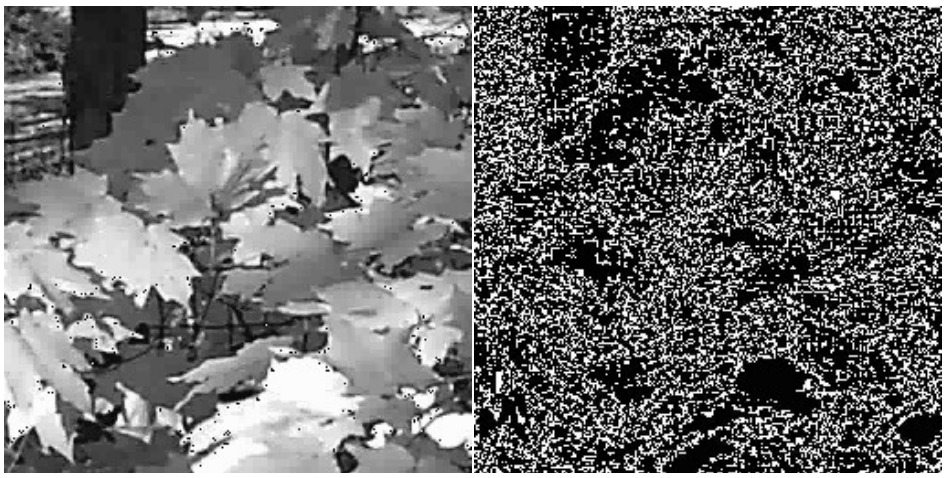
The significant advantages of digital signal transmission are accompanied by certain costs, primarily arising from the need to increase the bandwidth of telecommunication channels and the storage capacity of devices. This becomes practically infeasible due to the limited resources of telecommunication channels and storage devices, particularly in light of the growing demands of contemporary society for increased information throughput. This issue is particularly critical in digital image transmission and archiving systems for various applications (e.g., videotelephony, television, videoconferencing), due to the high information density of image signals. This challenge has led to the development of numerous methods for image signal compression, which enable digital image compression with varying levels of accuracy and are referred to as efficient coding techniques.

Although numerous scientific studies have been conducted globally, including in Georgia, on the effective coding of digital images using linear transformations, and recommendations for coding both static and dynamic images have been developed by the JPEG (Joint Photographic Experts Group) and MPEG (Moving Picture Experts Group), with relevant compression standards for static and dynamic images adopted by the International Organization for Standardization (ISO), the full potential of improving image coding efficiency using linear transformations remains unexplored. This is primarily because the coding process currently considers only the statistical and psychophysiological

characteristics of images and human vision. However, following the linear transformation of digital signals, the expansion of the dynamic range of transformation coefficients leads to what is known as matrix redundancy in the transformation space (transformant). The presence of this redundancy, a result of the algorithm's characteristics, can be exploited to increase the efficiency of both lossless and partial lossy image encoding. General principles of image coding based on linear transformations include: The statistical characteristics of image signals and the distinct features of human vision , their potential application in efficient coding systems based on linear transformations;

The primary scientific propositions formulated and substantiated in this article are as follows:

1. The effective digital lossless and partial lossy encoding of images based on the Walsh linear transform can be achieved through both statistical methods and the compression of matrix redundancy in the psychophysiological and transform spaces of human vision.
2. The presence of matrix redundancy in Walsh, Hadamard, Pell, and X-transformations arises from the expansion of the dynamic range of the transform coefficients relative to the original image elements. Compressing this redundancy also contributes to the reduction of the statistical redundancy in the image.
3. After applying digital encoding of signals using the Walsh transform and its variants, matrix redundancy is revealed to varying degrees within the set of all equally weighted sequences of the transform. This occurs when the defining number of image fragment sizes is equal to or greater than the number of symbols (bits) used to encode the elements of the original image.



(nxn=4x4; K_d=64; m_2=1,92 bits/e; F=4,17; RMSE=7,24;

NRMSE =0,05; SNR=26,38 db; PSNR=30,97 db)

Conclusion:

Given the aforementioned considerations, investigating the potential for enhancing the efficiency of both lossless and partial lossy image coding using the Walsh linear representation of digital image signals, as well as developing corresponding algorithms that leverage matrix redundancy in the

transform coefficient space (transformant), constitutes a significant and timely scientific and technical challenge.

References

1. Bernard Sklar. ,,Digital Communications: Fundamentals and applications''. Second Edition. Communications Engineering Services, Tarzana, California and University of California, Los Angeles. Prentice Hall P T R. Upper Saddle River, New Jersey 07458.
2. J. Khuntsaria, V. Steperman, L. Khuntsaria ,,Encoding Principles of signals source'', Publishing House "Technical University", 2009, 140 page
3. L. Khuntsaria Reducing matrix redundancy in the Walsh transform / Georgian Engineering News (GEN), N2, 2005

წრფივი გარდასახვების საფუძველზე გამოსახულებათა კოდირების სხვადასხვა ასპექტები

ლალი ხუნწარია

საქართველოს ტექნიკური უნივერსიტეტი, ენერგეტიკის ფაკულტეტი პროფესორი, დეკანის მოადგილე

ანოტაცია:

თანამედროვე მსოფლიო, რომელიც მეოთხე ინდუსტრიული რევოლუციის ეპოქაში ვითარდება, გლობალურ ეკონომიკას ქმნის. ის თავისთავად ითვალისწინებს განახლებული, ინტელექტუალური ტექნოლოგიების ინტეგრაციას წარმოებასთან, სამუშაო პროცესების სრულ ავტომატიზაციას, მანქანურ სწავლებას, ხელოვნური ინტელექტის თითქმის ყველა სფეროში გამოყენებას, კიბერუსაფრთხოების საკითხების გათვალისწინებას და მრავალი სხვა. აღნიშნული პროცესების შესაბამისად საინფორმაციო-სატელეკომუნიკაციო სფეროს დინამიური განვითარება, მეცნიერული სიახლეები და მათი პრაქტიკული ღირებულება აქტუალურ საკითხად რჩება. ერთ-ერთ ასეთ ამოცანათა რიცხვს მიეკუთვნება ბგერითი და ვიდეო სიგნალების ეფექტურად დამუშავების, შენახვის და გადაცემის საკითხებზე ჩატარებული კვლევები.

საკვანძო სიტყვები: წრფივი გარდასახვები, ელემენტური და ჯგუფური (ბლოკური, ფრაგმენტული) მეთოდები, მოძრავი გამოსახულებების კომპრესიის JPEG და MPEG სტანდარტები