

Modified parallel-hierarchical transformation algorithm for processing of optical imaging

Leonid Tymchenko^a, Natalia Kokriatska^a, Sergii Pavlov^b, Volodymyr Tverdomed^a,
Ilya Lisovenko^a, Irina Khomyuk^c, Natalia Koval^d, Ainur Ormanbekova^e, Żaklin Grądz^{*f},
Ingkar Issakozhayeva^g

^aState University of Infrastructure and Technology, Kyiv, Ukraine; ^bOptic-Electronic Systems Department, Vinnytsia National Technical University, Vinnitsa, Ukraine; ^cDepartment of Higher Mathematics the Vinnytsia National Technical University, Vinnitsa, Ukraine; ^dFinance and innovation management, Vinnitsa National Technical University, Vinnitsa, Ukraine, ^eAl Farabi Kazakh National University, Almaty, Kazakhstan; ^f Department of Electronics and Information Technology, Lublin University of Technology, Lublin, Poland; ^gSatbayev University, Almaty, Kazakhstan

ABSTRACT

This article presents the implementation of a modified parallel-pyramidal algorithm for the efficient processing and identification of images. The method involves creating a systemic model that supports spatial, temporal, and network data integration, forming a dynamic pyramidal-hierarchical network. The article details the techniques for sorting vectors, G-transformations for modifying vector elements, and the shifting procedure that facilitates efficient data transformation. The described procedures are integrated into the overall data processing sequence, which includes the iterative application of these methods until the final result is achieved.

Keywords: parallel-pyramidal transformation, image identification, image analysis, pyramidal-hierarchical network, shifting procedure, optical imaging

1. INTRODUCTION

This work presents the software implementation of an enhanced parallel-pyramidal transformation algorithm for image processing and identification. In the context of rapid technology development, the creation of innovative parallel processing environments using optical data is becoming increasingly relevant. The foundation of progress in the field of technical vision systems and image analysis is the emulation of human vision and the brain processes that occur during the processing of visual information. One of the challenges in recognizing dynamic images is the need to quickly process large volumes of data. Parallel approaches are used in various fields of science¹⁻². This is especially important in fields where laser technologies are applied, such as laser navigation and atmospheric-optical communications³⁻⁵. Interaction between humans and robots contributes to maintaining competitive production value through the harmonious combination of human skills and technological capabilities of robots⁶. However, an important task is the development of universal principles for the systematization and effective application of neural networks in various spheres of activity⁶⁻⁸.

2. MATERIALS AND METHODS OF RESEARCH

SORTING OF VECTORS.

Let's represent an array of data by a matrix A of dimension $m \times n$, where m is the number of rows, and n is the number of columns. Then A can be represented as⁹⁻¹¹:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}, \quad (1)$$

vectors of the matrix $v_1 = [a_{11}, a_{12}, \dots, a_{1n}]$, $v_2 = [a_{21}, a_{22}, \dots, a_{2n}]$, $v_m = [a_{m1}, a_{m2}, \dots, a_{mn}]$. Let v' be the vector resulting from sorting the vector v_i . In the sorted vector for any consecutive elements v'_i and v'_{i+1} of the vector v_i , where $i = 1, 2, \dots, n-1$, there are three variants of sorting elements: $v'_i \geq v'_{i+1}$, $v'_i \leq v'_{i+1}$, or permutation $v' = [v'_{\pi(1)}, v'_{\pi(2)}, \dots, v'_{\pi(n)}]$ where π represents a random permutation of the indices of vector v , and $\pi(i)$ denotes the index in v that is pointed to by the i -th element in the permuted vector. It is important to note that each element v_i from v appears exactly once in v' but the order of elements in v' is determined randomly. All possibilities for permuting the elements of v are equally probable. Formally, π is a function from the set of indices $\{1, 2, \dots, n\}$ to itself, satisfying the condition of bijection, and each value $\pi(i)$ is chosen randomly in such a way that every permutation is equally likely (algorithm (Fisher-Yates shuffle))¹²⁻¹⁵.

DESCRIPTION OF G-TRANSFORMATION OF VECTORS.

For each vector $v_m \in A$ an empty vector v'_m is created. To this vector modified element v'_{mn} are added, calculated as the product of the first nonzero element and the sum of nonzero elements in the vector¹⁶⁻¹⁹:

$$v'_{mn} = v_{i_f} \sum_{i=1}^n 1_{v_i \neq 0} . \quad (2)$$

Here, $i_f = \min\{j | v_j \neq 0, j = 1, \dots, n\}$ identifies the index of the first nonzero element in the vector, and $1_{v_i \neq 0}$ serves as the indicator function.

The transformation function applies to vector v_m as follows: if $i = i_f$, the vector element is set to 0, if $i > i_f$ and $v_i \neq 0$, the vector element is replaced with $v_i - v_{i_f}$

$$f(v) = \begin{cases} 0, & \text{if } i = i_f \\ v_i - v_{i_f}, & \text{if } i > i_f \text{ and } v_i \neq 0 \end{cases} . \quad (3)$$

In the transformed matrix A' , each element is defined by:

$$A' = \begin{bmatrix} a_{11} S_1 & (a_{12} - a_{11})(S_1 - 1) & \dots & (a_{1n} - a_{11})(S_1 - (n-1)) \\ a_{21} S_2 & (a_{22} - a_{21})(S_2 - 1) & \dots & (a_{2n} - a_{21})(S_2 - (n-1)) \\ \vdots & \vdots & \dots & \vdots \\ a_{m1} S_m & (a_{m2} - a_{m1})(S_m - 1) & \dots & (a_{mn} - a_{m1})(S_m - (n-1)) \end{bmatrix}, \quad (4)$$

where $S_m = \sum_{i=1}^n 1_{A_{mi} \neq 0}$ is the sum of nonzero elements of the vector A_m .

The actions are cyclically repeated until $\exists i \in \{1, 2, \dots, n\}: v_{mi} \neq 0$ for each vector. The obtained vectors are then combined into a new matrix $A_1 = [v'_1; v'_2; \dots; v'_m]$.

BIAS

The matrix A , of size $m \times n$, (where m represents the number of rows, and n the number of columns) is transformed into a new matrix B of size $m \times (n + m - 1)$. For each element $a_{ij} \in A$, where $i = 1, 2, \dots, m$, and $j = 1, 2, \dots, n$, its new position in matrix B is designated as $b_{i, (j+i-1)}$. All other elements in matrix B , which do not receive a value from A , are initialized as 0. The element a_{11} is selected from matrix A , and the first column is removed¹⁸⁻²⁰.

For every column j , where $j = 1, 2, \dots, n$, it is determined whether the condition $\forall i \in \{1, 2, \dots, m\}, M_{ij} = 0$ is satisfied. If this condition holds, indicating the entire column j contains zeros, it is required to be eliminated from the matrix. Subsequent to the deletion of one or more columns, the matrix's dimensions are modified to $m \times n'$, with $n' \leq n$.

In a similar vein, for every row i where $i = 1, 2, \dots, n$, it is verified whether the condition $\forall j \in \{1, 2, \dots, n'\}, M_{ij} = 0$ is fulfilled. Should this condition be met, signifying that row i is comprised solely of zeros, its removal from the matrix is necessitated. Following the elimination of one or more rows, the dimensions of the matrix are adjusted to $m' \times n'$, where $m' \leq m$.

• C++ code implementation of the shift function

// Function to shift the elements of a matrix diagonally to the right

```
std::vector<std::vector<int>>> shiftMatrixDiagonally(const std::vector<std::vector<int>>>& matrix) {
```

```

if (matrix.empty()) return {}; // Check for an empty matrix
int numRows = matrix.size();
// Calculating the number of columns in the new matrix
int numCols = matrix[0].size() + numRows - 1;      std::vector<std::vector<int>>> shiftedMatrix(numRows,
std::vector<int>(numCols, 0)); // Creating a new matrix with zeros

for (int i = 0; i < numRows; ++i) {
    for (int j = 0; j < matrix[i].size(); ++j) {
// Filling the new matrix taking into account the shift
        shiftedMatrix[i][j + i] = matrix[i][j];
    }
}
shiftedMatrix = removeLastColumnIfAllZeros(shiftedMatrix);
return shiftedMatrix;
}

```

GENERAL SEQUENCE

The overall process follows a sequence where A' is obtained through the application of three functions on matrix A

$$A' = t \left(g(s(A)) \right), \quad (5)$$

where $s(A)$ denotes the sorting function applied to matrix A , $g(A)$ represents the G-transformation function, $t(A)$ signifies the transposition function.

Then iteratively:

$$\sum_{i=1}^m \sum_{j=1}^n [A_{ij} \neq 0] = 1 \quad (6)$$

Within each iteration, A' undergoes an update according to the formula:

$$A' = t \left(h \left(g(s(A')) \right) \right) \quad (7)$$

In this iterative step, A' is the matrix that is continually updated, and $h(A)$ is the bias function introduces a bias function into the sequence²⁰.

C++ CODE IMPLEMENTATION OF THE ALGORITHM

```

// Sorting vectors in the matrix
matrix = shuffleRows(matrix);

// First iteration of G-transformation of the matrix
matrix = gTransformation(matrix);

// Transposition
matrix = transpose(matrix);

```

```

int cnt = 2;
while (matrix.size() != 0) {
    //G-transformation of a matrix
    matrix = shuffleRows(matrix);
    matrix = gTransformation(matrix);

    // Bias
    matrix = shiftMatrixDiagonally(matrix);

    // Outputting the tail element
    resultVec.push_back(matrix[0][0]);
    matrix = removeFirstColumnFromMatrix(matrix);

    // Transposition
    matrix = transpose(matrix);
    cnt++;
}

```

3. NUMERICAL EXAMPLE OF THE IMPLEMENTATION OF THE MODIFIED PARALLEL-HIERARCHICAL TRANSFORMATION ALGORITHM FOR PROCESSING OF OPTICAL IMAGING

Input Information Matrix

$$M = \begin{bmatrix} 1 & 6 & 3 \\ 3 & 14 & 3 \\ 20 & 16 & 9 \\ 20 & 17 & X \end{bmatrix}. \quad (8)$$

Transposed matrix

$$M^T = \begin{bmatrix} 1 & 3 & 20 & 20 \\ 6 & 14 & 16 & 17 \\ 3 & 3 & 9 & X \end{bmatrix}. \quad (9)$$

First Iteration

$$M_1 = \begin{bmatrix} 4 & 6 & 34 & X \\ 24 & 24 & 4 & 1 \\ 9 & 6 & X & X \end{bmatrix} \quad M_1^T = \begin{bmatrix} 4 & 24 & 9 \\ 6 & 24 & 6 \\ 34 & 4 & X \\ X & 1 & X \end{bmatrix} \quad \text{sorted } M_1^T = \begin{bmatrix} 4 & 9 & 24 \\ 6 & 6 & 24 \\ 4 & 34 & X \\ 1 & X & X \end{bmatrix}. \quad (10)$$

Second Iteration

$$M_2 = \begin{bmatrix} 12 & 10 & 15 \\ 18 & 18 & X \\ 8 & 30 & X \\ 1 & X & X \end{bmatrix} \quad \text{bias } M_2 = \begin{bmatrix} 12 & 10 & 15 & X \\ X & 18 & 18 & X \\ X & X & 8 & 30 \\ X & X & X & 1 \end{bmatrix} \Rightarrow a_{11}^1 = 12$$

$$M_2 = \begin{bmatrix} 10 & 15 & X \\ 18 & 18 & X \\ X & 8 & 30 \\ X & X & 1 \end{bmatrix} M_2^T = \begin{bmatrix} 10 & 18 & X & X \\ 15 & 18 & 8 & X \\ X & X & 30 & 1 \end{bmatrix} \text{ sorted } M_2 = \begin{bmatrix} 10 & 18 & X \\ 8 & 15 & 18 \\ 1 & 30 & X \end{bmatrix} \quad (11)$$

Further iterations follow similarly

$$M_3 = \begin{bmatrix} 20 & 8 & X & X \\ X & 24 & 14 & 3 \\ X & X & 2 & 29 \end{bmatrix} \Rightarrow a_{11}^2 = 20, \quad (11)$$

$$M_4 = \begin{bmatrix} 16 & 16 & X & X \\ X & 4 & 12 & 0 \\ X & X & 6 & 26 \end{bmatrix} \Rightarrow a_{11}^3 = 16, \quad (12)$$

$$M_5 = \begin{bmatrix} 8 & 12 & X \\ X & 12 & 6 \\ X & X & 26 \end{bmatrix} \Rightarrow a_{11}^4 = 8, \quad (13)$$

$$M_6 = \begin{bmatrix} 24 & X & X \\ X & 12 & 20 \end{bmatrix} \Rightarrow a_{11}^5 = 24, \quad (14)$$

$$M_7 = \begin{bmatrix} 12 & X \\ 0 & 20 \end{bmatrix} \Rightarrow a_{11}^6 = 12 \quad (15)$$

$$M_8 = 20 \Rightarrow a_{11}^7 = 20 \quad (16)$$

For this numerical case, the main property of the PI network used for its training procedure:

$$\sum_{i=1}^3 \sum_{j=1}^4 M_{j,i} = 112 \quad \sum_{i=1}^7 a_{11}^i = 112 \quad (17)$$

4. CONCLUSION

This work makes a significant contribution to the development of methods for processing and identifying images, proposing an effective algorithmic approach based on parallel-pyramidal data processing. This new approach paves the way for the development of adaptive sorting methods that take into account the specificity of the data before processing, which, as demonstrated by previous research, can lead to more optimal solutions with a reduced number of iterations. The application of an adaptive sorting mask contributes to achieving these results, opening new prospects for improving the quality and efficiency of image processing across a wide range of applications, including computer vision and optical communication analysis.

ACKNOWLEDGEMENTS

This research has been is funded by the National Research Fund of Ukraine (Grant No. 2022.01/013).

REFERENCES

- [1] Kudinov, A., Antimirov, Y., Tyshchenko, I., Popova, M. and Cherepanov A. "The implementation of the parallel scrambler scheme for the IEEE 802.11 standard," NTL Journal of Electronics and Telecommunications 64(1), 91-94 (2018).
- [2] Byczkowska-Lipińska, L. , Stakhiv, P. and Cegielski, M. "Implementation of parallel algorithm of computations of dynamic processes in cluster systems," Przegląd Elektrotechniczny 86(1), 20-22 (2010).
- [3] Timchenko, L. I., Kokryatskaya, N. I., Melnikov, V. V. and Kosenko G. L. "Method of forecasting energy center positions of laser beam spot images using a parallel hierarchical network for optical communication systems," Optical Engineering 52(5), (2013). DOI: 1117/1.OE.52.5.055003.
- [4] Timchenko, L. I. and Nakonechna, S. S. "Image processing of laser beam spots using parallel-hierarchical networks," ScienceRise 3/2(3), (2014). DOI: 10.15587/2313-8416.2014.27536

- [5] Timchenko, L. I., Tverdomed, V. M., Kokryatska, N. I and Petrovsky, N. "Development of a method of processing images of laser beam bands with the use of parallel hierarchic networks," *Eastern-European Journal of Enterprise Technologies*. 9 (102), 21-27, (2019).
- [6] Tsarouchi, P., Spiliotopoulos, J., Michalos, G., Koukas, S., Athanasatos, A., Makris, S. and Chryssolouris, G. "A decision making framework for human robot collaborative workplace generation," *Procedia CIRP* 44, 228–232 (2016). <https://doi.org/10.1016/j.procir.2016.02.103>
- [7] Weiss, M. A. "Data structures and algorithm analysis in C++," Florida International University, Fourth edition, (2014). ISBN-13: 978-0-13-284737-7
- [8] Kleinberg, J. and Tardos, E., "Algorithm Design," Cornel University, Fourth edition, (2006). ISBN 0-321-29535-8
- [9] Orlov, D. A. and Neverova, E. A. "Determination of the position of the center of a laser beam when the dynamic range of the matrix receiver is exceeded," *Measurement Techniques* 10 (53), 1140–1146 (2011). DOI: 10.1007/s11018-011-9631-1
- [10] Kozhem'iako, V. P., Tymchenko, L. I. and Yarovyj, A. A. "Parallelhierarchical network as a structural and functional basis for building specialized models shaped computer," *Vinnytsia: Universum-Vinnytsia*, 161 (2005).
- [11] Timchenko, L. I., Pijarski, P., Zavadskiy, V., Nakonechna, S. S. and Kokriatskaya, N. I. "Processing laser beam spot images using the parallel-hierarchical network for classification and forecasting their energy center coordinates," *Proc. SPIE 10031, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments*, 2016, 1003110 (2016);
- [12] Timchenko, L., Kokriatskaia, N., Tverdomed, V., Horban, A., Sobovyi, O., Pogrebniak, L., et al. "Neurobiological properties of the structure of the parallel-hierarchical network and its usage for pattern recognition," *Informatyka, Automatyka, Pomiar w Gospodarce i Ochronie Środowiska* 14(3), 35–38 (2024). <https://doi.org/10.35784/iapgos.6212>
- [13] Gladun, V. P. "Growing pyramidal networks," *Shtuchniy Intelkt – Artificial Intelligence News*. 1, 30-40 (2004).
- [14] Poplavskiy, A. A., Timchenko, L. I., Kokryatskaya, N. I. and Poplavskiy, A. V. "Using gradient masks for the rapid determination of the centers of spot images of laser beams with high accuracy," *Shtuchniy Intelkt, Artificial Intelligence* 3, 422–426 (2010).
- [15] Tymchenko, L., Petrovskiy, M., Kokryatskaya, N., Gubernatorov, V. and Kutaev, Y. "Modeling of the high-performance PLD-based sectioning method for classification of the shape of optical object images," *Journal of Springer Plus* 2(692), (2013). DOI: 10.1186/2193-1801-2-692
- [16] Turlykozhaeva, D., Akhtanov, S., Ussipov, N., Akhmetali, A., Bolysbay, A. and Shabdan, Y. "Routing Algorithm for Software Defined Network Based on Boxcovering Algorithm," In *2023 10th International Conference on Wireless Networks and Mobile Communications (WINCOM)*, IEEE, 1-5 (2023).
- [17] Hotra, O., Kovtun, S., et al. "Prospects for the Application of Wavelet Analysis to the Results of Thermal Conductivity Express Control of Thermal Insulation Materials," *Energies* 14(17), 5223 (2021).
- [18] Turlykozhaeva, D., Ussipov, N., Baigaliyeva, et al. "Routing metric and protocol for wireless mesh network based on information entropy theory," *Eurasian Physical Technical Journal* 4 (46), 90-98 (2023).
- [19] Isaieva, O. A., Avrunin, O. G., Moroz, I. I., Stoliarenko, O. V., et al. "Features of image analysis under UV-video dermoscopy," *Proc. SPIE 11456, Optical Fibers and Their Applications 2020*, 114560H (12 June 2020); 11456 doi:10.1117/12.2569774
- [20] Kolobrodov V. G., Miheenko L. A., Mykytenko V. I., et al. "Computer-integrated technology of space television cameras radiometric calibration," *Proc. SPIE 12040, Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2021*, 120400V (3 November 2021); DOI: 10.1117/12.2617508