***Results from research project – stage 2***

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| ***Contract No:***  КP-06-Н27/16 |
| ***Initial and final date of the project:***  8.7.2021 г. – 8.1.2023 г |
| ***Project title:***  **Development of efficient methods and algorithms for tensor-based processing and analysis of multidimensional images with application in interdisciplinary areas** |
| ***Research organization:***  Technical University of Sofia  ***Partner organizations:*** |
| ***Principle investigator:***  Competition for financial support of basic research projects – 2018 |
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| ***Publication from the project*** |
| **For each publication, please, provide:**   * Bibliographic information *(for journals with IF, please, provide the IF of the journal in the year of publication)* * Internet link to the publication in the electronic version of the journal and/or link to publically accessible electronic version of the publication |
| 1. R. Kountchev, R. Mironov, R. Kountcheva. Third-Order Tensor Decorrelation Based on 3D FO-HKLT with Adaptive Directional Vectorization. MDPI Symmetry, May 2022, Vol. 14, Issue 5, 854. Special Issue “Multidimensional Signal Processing and Its Applications”, Eds. R. Kountchev, R. Mironov. Open Access Journal, (IF: 2.7, H-Index 24, SJR 0.483, CiteScore 4.9, Rank Q1). ISSN: 2073-8994, DOI: 10.3390/sym14050854. |
| 2. R. Kountcheva, R. Mironov, R. Kountchev. MLTSP: New 3D Framework, Based on the Multilayer Tensor Spectrum Pyramid. MDPI Symmetry, September 2022, Vol. 14, Issue 9, 1909. Section “Computer”. Open Access Journal, (IF: 2.7, H-Index 24, SJR 0.483, CiteScore 4.9, Rank Q1). ISSN: 2073-8994, DOI: 10.3390/sym14091909. |
| 3. R. Kountchev, R. Mironov, A. Bekiarski, S. Pleshkova. A Method for Local Contrast Enhancement of Endoscopic Images Based on Color Tensor Transformation into a Matrix of Color Vectors’ Modules Using a Sliding Window. MDPI Symmetry, September 2022, Vol. 14, Issue 12, 2582. Section “Computer”. Open Access Journal, (IF: 2.7, H-Index 24, SJR 0.483, CiteScore 4.9, Rank Q1). ISSN: 2073-8994, DOI: 10.3390/sym14122582.. |
| 4. R. Kountchev, R. Mironov, R. Kountcheva. Analysis of the Recursive Locally-Adaptive Filtration of 3D Tensor Images. MDPI Symmetry, August 2023, Vol. 15, Issue 8, 1493. Special Issue “Multidimensional Signal Processing and Deep Learning - Symmetry Approach”, Eds. R. Mironov, R. Kountcheva. Open Access Journal, (IF: 2.7, H-Index 24, SJR 0.483, CiteScore 4.9, Rank Q1). ISSN: 2073-8994, DOI: 10.3390/sym15081493. |
| 5. R. Kountchev, R. Kountcheva. Hierarchical Decomposition of Third-order Tensor trough Adaptive Branched Inverse Difference Pyramid Based on 3D-WHT. Proceedings of 2nd International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2021), July 2021, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, K. Nakamatsu, Springer, 2022, Smart Innovation, Systems and Technologies, SIST, Vol. 270, pp. 49-61. ISSN: 2190-3018, (Print), ISBN: 978-981168557-6. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). DOI: https://doi.org/10.1007/978-981-16-8558-3\_3. |
| 6. R. Kountcheva, R. Kountchev. Equalization of Directional Multidimensional Histograms of Matrix and Tensor Images, Proceedings of 2nd International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2021), July 2021, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, K. Nakamatsu, Springer, 2022, Smart Innovation, Systems and Technologies, SIST, Vol. 270, pp. 97-111. ISSN: 2190-3018, (Print), ISBN: 978-981168557-6. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). DOI: https://doi.org/10.1007/978-981-16-8558-3\_7. |
| 7. I. Draganov, R. Mironov. Object motion detection in video by fusion of RPCA and NMF decompositions, Proceedings of 2nd International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2021), July 2021, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, K. Nakamatsu, Springer, 2022, Smart Innovation, Systems and Technologies, SIST, Vol. 270, pp. 35-47. ISSN: 2190-3018, (Print), ISBN: 978-981168557-6. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). DOI: https://doi.org/10.1007/978-981-16-8558-3\_2. |
| 8. I. Draganov, R. Mironov. Moving Objects Detection in Video by Various Background Modelling Algorithms and Score Fusion. Proceedings of 14th International KES Conference on Intelligent Decision Technologies, KES-IDT 2022, June 20-22, 2022, Rhodes, Greece. In: Intelligent Decision Technologies, Eds. I. Czarnowski, R. J. Howlett, L. C. Jain, Springer, 2022, Smart Innovation, Systems and Technologies, SIST, Vol 309, pp. 347–359. ISSN: 2190-3018, ISBN: 978-981193443-8. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4), DOI: 10.1007/978-981-19-3444-5\_30. |
| 9. R. Kountchev, R. Kountcheva. Decorrelation of a Sequence of Color Images through Hierarchical Adaptive Color KLT. Proceedings of 14th International KES Conference on Intelligent Decision Technologies, KES-IDT 2022, June 20-22, 2022, Rhodes, Greece. In: Intelligent Decision Technologies, Eds. I. Czarnowski, R. J. Howlett, L. C. Jain, Springer, 2022, Smart Innovation, Systems and Technologies, SIST, Vol 309, pp. 333-346. ISSN: 2190-3018, ISBN: 978-981193443-8. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4), DOI: 10.1007/978-981-19-3444-5\_29. |
| 10. I. Draganov, R. Mironov. Video Tracing of Moving Objects by Fusing Three-Term Decompositions. Proceedings of 3rd International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2022), July 7-9, 2022, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, K. Nakamatsu, Springer, 2023, Smart Innovation, Systems and Technologies, SIST, Vol. 332, pp. 10-22. ISSN: 2190-3018, (Print), ISBN: 978-981197841-8. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). DOI: 10.1007/978-981-19-7842-5\_2. |
| 11. R. Kountchev, R. Kountcheva. Tensor Spectral Pyramid for Color Video Sequences Representation, Based on 3D FO-AHKLT. Proceedings of 3rd International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2022), July 7-9, 2022, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, K. Nakamatsu, Springer, 2023, Smart Innovation, Systems and Technologies, SIST, Vol. 332, pp. 31-43. ISSN: 2190-3018, (Print), ISBN: 978-981197841-8. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). DOI: 10.1007/978-981-19-7842-5\_4. |
| 12. V. Georgieva, V. Gardeva. Adaptive algorithm for CT images enhancement to improve the diagnosis of lung diseases. AIP Conference Proceedings, Applications of Mathematics in Engineering and Economics (AMEE’22), Sofia, June 7-13, 2022, Vol. 2939, Issue 1, Article number 020003. (SJR 0.164, H-Index 18, CiteScore Rank Q4). ISBN: 978-073544763-9. DOI: 10.1007/978-981-19-3444-5\_30. |
| 13. L. C. Jain, R. K. Kountchev, R. A. Kountcheva. Deep Representation and Analysis of Visual Information, Based on the IDP Decomposition. Proceedings of 4th International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2023), July 6-8, 2023, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, I. Draganov, R. Kountcheva, K. Nakamatsu, Springer, 2024, Smart Innovation, Systems and Technologies, SIST, Vol 385, Chapter 1. ISSN: 2190-3018, (Print), ISBN: 978-981-97-0108-7. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). (In Print, 04 April 2024) |
| 14. V. Georgieva, D. Tsvetkova. Some Trends in Application of Geometric Approaches in Multimodal Medical Image Fusion. Proceedings of 4th International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2023), July 6-8, 2023, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, I. Draganov, R. Kountcheva, K. Nakamatsu, Springer, 2024, Smart Innovation, Systems and Technologies, SIST, Vol 385, Chapter 2. ISSN: 2190-3018, (Print), ISBN: 978-981-97-0108-7. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). (In Print, 04 April 2024) |
| 15. L. C. Jain, R. K. Kountchev, R. A. Kountcheva. Locally Adaptive Processing of Color Tensor Images Represented as Vector Fields. Proceedings of 4th International Workshop on New Approaches for Multidimensional Signal Processing (NAMSP 2023), July 6-8, 2023, Sofia, Bulgaria. In: New Approaches for Multidimensional Signal Processing, Eds. R. Kountchev, R. Mironov, I. Draganov, R. Kountcheva, K. Nakamatsu, Springer, 2024, Smart Innovation, Systems and Technologies, SIST, Vol 385, Chapter 2. ISSN: 2190-3018, (Print), ISBN: 978-981-97-0108-7. Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). (In Print, 04 April 2024) |
| 16. R. Kountcheva, R. Mironov, I. Draganov. Digital Twin Technology Approach Based on the Hierarchical IDP Tensor Decomposition. Proceedings of the Fifth International Conference on 3D Imaging Technologies - Multidimensional Signal Processing and Deep Learning, 3DIT-MSP&DL, Changsha, December 2023, China. In: Multidimensional Signal Processing: Methods and Applications, Eds. R. Kountchev, S. Patnaik, Y. Liu, R. Kountcheva, Springer, 2024, Smart Innovation, Systems and Technologies, SIST, ISSN: 2190-3018, (Print). Books from this series are indexed in ISI Proceedings, EI-Compendex, SCOPUS, Google Scholar and Springerlink, (SJR 0.17, H-Index 18, CiteScore Rank Q4). (In Print 2024) |
| 17. I. Draganov, R. Mironov. Gaussian Adaptive Filtering of Low Resolution Video Using Anisotropic Tensor. 29th National Conference with International Participation “TELECOM 2021”. October 28 - 29, 2021, Sofia, Bulgaria, pp. 133-136. Proc. IEEE, 2021. Indexed in SCOPUS, Google Scholar. ISBN: 978-166543344-0. DOI: 10.1109/TELECOM53156.2021.9659687. |
| 18. P. Petrov. An Adaptive Pan-Tilt Camera Control for Visual Target Tracking. 29th National Conference with International Participation “TELECOM 2021”. October 28 - 29, 2021, Sofia, Bulgaria, pp. 125-128. Proc. IEEE, 2021. Indexed in SCOPUS, Google Scholar. DOI: 10.1109/TELECOM53156.2021.9659665. |
| 19. V. Georgieva, P. Petrov, D. Tsvetkova, L. Laskov. MRI/SPECT Image Fusion of Brain Based on Multi-Scale Wavelet Decomposition. Proceedings of 56th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST 21), June 16-18, 2021, Sozopol, Bulgaria, pp. 85-88. Proc. IEEE, 2021. ISSN: 2603-3259 (Print), ISSN: 2603-3267 (Online), ISBN: 978-166542887-3. Indexed in SCOPUS, Google Scholar. DOI: 10.1109/ICEST52640.2021.9483476. |
| 20. I. Draganov, R. Mironov. Filtering of X-Ray Images using Nonlinear Isotropic Diffusion. Proceedings of 57th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST 22), June 16-18, 2022, Ohrid, North Macedonia, pp. 85-88. Proc. IEEE, 2021. ISSN: 2603-3259 (Print), ISSN: 2603-3267 (Online), ISBN: 978-166548500-5. Indexed in SCOPUS, Google Scholar. DOI: 10.1109/ICEST55168.2022.9828716. |
| 21. R. Mironov, I. Draganov. Comparative Analysis of Local Adaptive LMS Image Filtration. Proceedings of 58th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST 23), June 29 - Jule 1, 2023, Nish, Serbia, pp. 29-32. Proc. IEEE, 2021. ISSN: 2603-3259 (Print), ISSN: 2603-3267 (Online), ISBN: 979- 835031073-3. Indexed in SCOPUS, Google Scholar. DOI: 10.1109/ICEST58410.2023.10187379. |
| 22. D. Tsvetkova, V. Georgieva. GUI for image fusion in medical images of brain. Proceedings of 15th International Conference on Communications, Electromagnetism and Medical Applications (CEMA’21), Athens, October 21, 2021, pp. 43-47, ISSN: 1314-2100. Indexed in SCOPUS, Google Scholar. |
| 23. I. Draganov, R. Mironov. Objects Tracking from Video in Urban Environment by Low Rank Recovery. Proceedings of 15th International Conference on Communications, Electromagnetism and Medical Applications (CEMA’21), Athens, October 21, 2021, pp. 58-62, ISSN: 1314-2100. Indexed in SCOPUS, Google Scholar. |

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| ***Main results from the research project*** |
| In relation to the set goal and according to the work program, during the second stage of the contract, scientific research was carried out corresponding to the relevant activities planned in work packages RP4, RP5 and RP6. As a result of the research carried out under RP4 and RP5, the following new methods and algorithms were modeled and tested for: Third-order tensor decorrelation based on 3D FO-HKLT with adaptive directed vectorization; Three-dimensional structure based on Multi-Layer Tensor Spectrum Pyramid (MLTSP); Hierarchical decomposition of third-order tensors by adaptive branched inverse difference pyramid using 3D-WHT; Tensor spectral pyramid for representation of color video sequences by 3D FO-АHKLT; Enhancing the contrast of endoscopic images by transforming the color tensor into the modulus matrix of the color vectors, using a sliding local window; Equalization of the directional multidimensional histograms of matrix and tensor images; Locally adaptive processing of color tensor images represented as vector fields; Adaptive Gaussian low-resolution video filtering by anisotropic tensor; X-ray image filtering by nonlinear isotropic diffusion; Video Tracking of Moving Objects by Fusion of Trinomial Decompositions; Adaptive improvement of the quality of tomographic images, in order to improve the diagnosis of lung diseases; MRI/SPECT brain image fusion based on multidimensional wavelet transform; Video object tracking in an urban environment using low-rank recovery; Decorrelation of Color Image Sequences by Hierarchical Adaptive KLT; Deep representation and analysis of visual information based on IDP decomposition.  At the same time, the following analyzes of the results of the work of the developed algorithms and programs were carried out: Technological approach for virtual modeling of real systems, based on hierarchical IDP tensor decomposition; Recursive Locally Adaptive Filtering Analysis of 3D Tensor Images; Comparative analysis of locally adaptive LMS filtration; Analysis of moving objects in video by fuzzy RPCA and NMF decomposition; Analysis of moving objects in video using different background modeling algorithms and Score Fusion.  This made it possible, in addition, to develop additional programs and graphical interfaces for: the application of geometric approaches in combining multimodal medical images; Medical Brain Image Fusion GUI; Adaptive Pan-Tilt Camera Control for Visual Target Tracking.  The developed mathematical models and decomposition algorithms are compared with similar ones in the world scientific literature and are shown to possess lower computational complexity, greater flexibility in terms of choosing the number of levels for hierarchical decomposition, and possess greater efficiency in terms of of the concentration of energy in the first components of the decomposition. This allows these decompositions to be the basis of new methods for compression and processing of multidimensional images. The evaluation of the performance of the developed algorithms for hierarchical decomposition showed in theoretical and practical aspects that, thanks to their lower computational complexity, they can be more efficient in terms of their use in multidimensional databases.  The developed mathematical models and algorithms for multidimensional interpolation and filtration are compared with similar ones in the world scientific literature and are shown to have lower computational complexity, greater flexibility in terms of algorithm parameter selection, and are suitable for use in the developed tensor decompositions. the methods can be applied to different types of multidimensional data (images).  The developed mathematical models and algorithms for hierarchical object segmentation in MDI have been compared with similar algorithms in the world scientific literature and shown to have significant advantages in terms of greater flexibility of human organ size measurement templates in medicine and more further segmentation and 3D visualization. The experiments carried out during the implementation of an optical method for tracking the trajectory of a mobile robot with a differential drive confirm the validity of the constructed mathematical model using matrix methods.  The comparison of the developed methods and algorithms during the second stage of scientific research shows that the main tasks formulated in the plan have been overachieved. The evaluation of the experimental results makes it possible to formulate recommendations for their effective application in various areas of the processing of multidimensional images and video sequences, depending on the specific requirements. The obtained results have been discussed at various scientific forums and have been shaped in a total of 23 publications in journals, volumes of books and in conference proceedings, all indexed in SCOPUS, Google Scholar and other global databases. |