UDC 004.8 **Digital technologies: IT solutions, automation, artificial intelligence**

NEURAL NETWORK CLASSIFICATION OF TEXTILES BY FIBER FEATURES USING MICROSCOPIC IMAGES

O.O. ZALUTSKA
Khmelnytskyi National University

The relevance of the study is due to the need to increase the technological capacity of textile sorting systems in the logic of the circular economy, where the correct distinction between natural and synthetic fibers determines the purity of fractions, the suitability of secondary raw materials and the economics of recycling [1]. The significant volumes of textile waste in the EU, the limitations of manual procedures and errors in mixing fibers of different nature indicate a lack of effective automated solutions capable of operating at a stable level of accuracy in industrial conditions. This creates a scientific and practical demand for deep learning methods that operate with realistic input data, have a standardized training and evaluation protocol and ensure the reproducibility of results and their transfer to production conveyors for sorting textile waste [2]. Within the framework of such a demand, microscopic images in the visible spectrum act as a source of informative textural and morphological features relevant for automated classification by fiber nature.

The aim of the work is to substantiate and empirically verify a reproducible method for binary classification of textiles by fiber nature based on microscopic images in the visible spectrum. The methodology is based on an open sample corpus and a unified training protocol, which allows obtaining comparable results for different modern computer vision architectures, and also creates the prerequisites for technological integration into sorting lines and laboratory quality control systems. The central point is to maintain a balance between accuracy, hardware resource requirements and procedural transparency, which directly affects the scalability and portability of solutions.

The empirical base is formed as an open set of microscopic images of 1024×1024 pixels, obtained using a digital microscope with a working distance of 6.5 cm and a built-in system of five LEDs, which provides uniform illumination of the fabric surface at an intensity of 400-420 lux. White balance and exposure were adjusted manually to achieve color stability and contrast between samples. The corpus includes 3,107 images, of which 1,547 represent natural fabrics and 1,560 represent synthetic fabrics; data collection included capturing the front and back sides of the fabrics, as well as light deformations (twisting, stretching, wrinkles), which increases representativeness and brings the training conditions closer to real-world use. The sample is structured in two directories (“synthetic”, “natural”) with an 80/20 split into training and validation subsets. This data organization provides sufficient diversity of texture patterns and reduces the risk of the model being retrained to narrow class-specific features. The classification pipeline involves standardized image preparation, within which all samples are scaled to 224×224 pixels with subsequent normalization by the mean and standard deviation of the channels. To increase the generalization ability, light augmentations were applied that simulate real variations in shooting conditions [3]: random horizontal reflection, rotation in the range of ±10°, smooth scaling. The set of these procedures is aimed at stabilizing the behavior of the model with respect to changes in fiber orientation, local shadows and small deformations of the canvas. The training stage is implemented on unified hyperparameters: batch size 32, AdamW optimizer with a weight regulator of 1×10^{-2}, two-class cross-entropy loss function, additional regularizer dropout=0.1; training duration 10 epochs with a division of 80/20, which allows for correct comparison of architectures without changing the configuration.

The computing platform is a laptop NVIDIA GeForce RTX 3050 (CUDA 12.1, 4 GB), which is a realistic lower bar for implementations in educational and production laboratories.

Comparative analysis is performed for three modern architectures representing different paradigms of computer vision [4]: Vision Transformer (ViT-B/16) [5] with self-attention mechanisms for modeling global dependencies [6], EfficientNet-B0 [7] with combined depth/width/resolution scaling, and ConvNeXt-Tiny [8] as a modern convolutional architecture with a reformulated block topology. The single training protocol eliminates the influence of configuration differences and allows interpreting the difference in metrics as a consequence of architectural properties, rather than different settings. In this way, a consistent approach to the accuracy limits of validation [9] is demonstrated, which indicates the relevance of microscopic features for the problem of natural/synthetic distinction and the potential for scaling the solution in production scenarios [10]. The problem statement captures several barriers that have historically limited the development of textile classification methods by fiber nature: the lack of open sets for independent verification, the dominance of classification tasks by weave structure instead of fiber type analysis, and the lack of reproducibility of previous works. In the proposed scheme, these barriers are overcome due to the openness of the data, a clear protocol for forming subsamples, and standardized training parameters, which allows building correct comparisons and translating the method into practical domains without loss of quality. Special attention is paid to the variability of the types of shooting, extraneous artifacts, and deformations of the canvas, which form classically “heavy” subsets; taking these factors into account at the stage of building the data corpus reduces the risk of retooling to a narrow subspace of features and increases the stability of metrics.

The problem statement captures several barriers that have historically limited the development of textile classification methods by fiber nature: the lack of open sets for independent verification [11], the dominance of classification problems by weave structure instead of fiber type analysis, and the lack of reproducibility of previous works. In the proposed scheme, these barriers are overcome due to the openness of the data, a clear protocol for forming subsamples, and standardized training parameters, which allows building correct comparisons and translating the method into practical domains without loss of quality. Special attention is paid to the variability of survey types, extraneous artifacts, and fabric deformations that form classically “heavy” subsets; taking these factors into account at the stage of building the data corpus reduces the risk of retooling to a narrow subspace of features and increases the stability of metrics.

The practical relevance of the results lies in the possibility of direct application of the methodology in the tasks of sorting textile waste, laboratory confirmation of fabric composition and incoming quality control. For a circular economy, it is important not only to maximize the average accuracy, but also to stabilize the behavior of the model in different types of scenes, in particular in the presence of wrinkles, light fiber overlaps and local highlights. The open nature of the data and the unified protocol reduce the barriers to industry implementations and allow systems to be validated by independent parties, supporting the requirements for transparency and interoperability. Taking into account computational limitations and demonstrating correct operation on laptop graphics indicate a realistic cost profile for educational and production units, which is critical for scaling solutions in a network of sorting nodes. To test the developed methodology, a software prototype was developed, shown in Fig. 1.

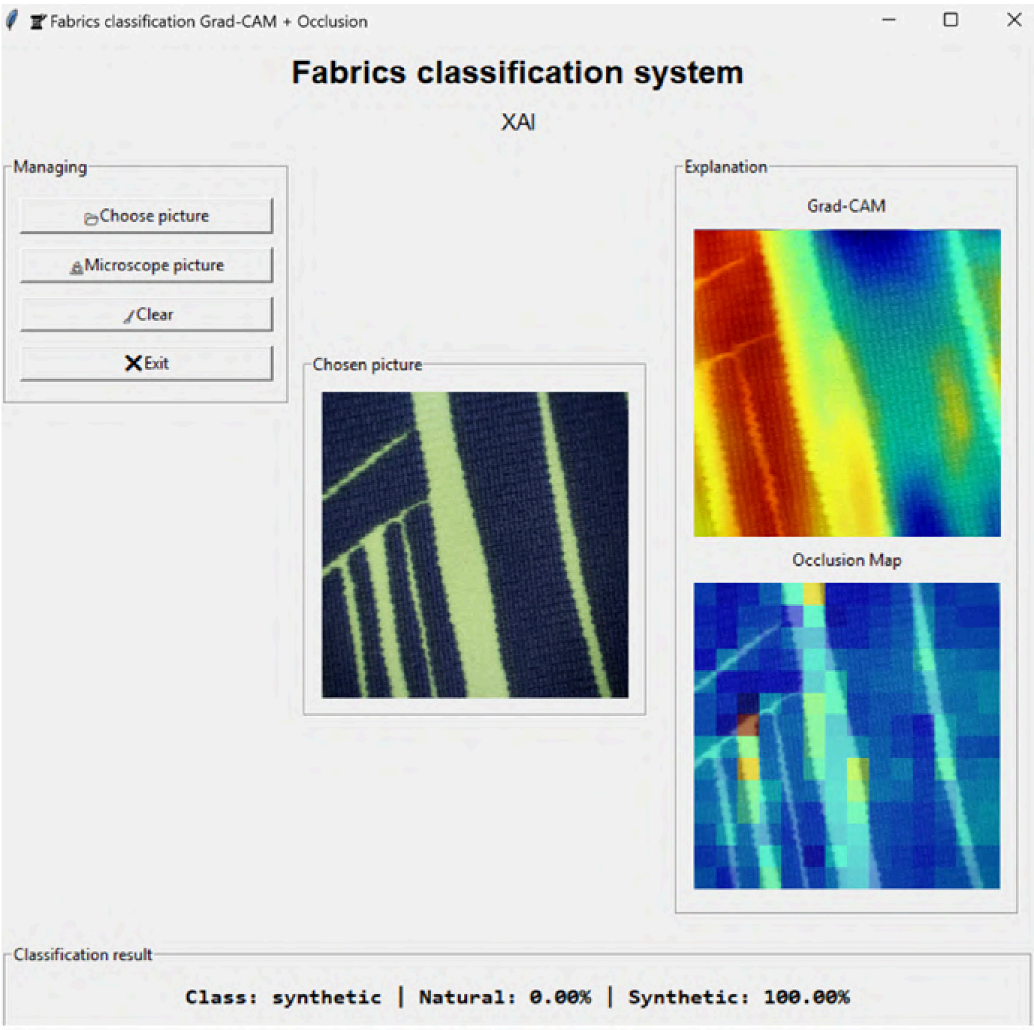

Fig. 1. Example of the developed application

The connection with the goals of sustainable development is manifested through a direct contribution to responsible consumption and production, reducing the burden on municipal solid waste landfills and increasing the purity of secondary fractions. The methodological emphasis on data openness and reproducibility of protocols is consistent with the innovative development of industry partnerships, as it facilitates technology transfer between academic and industrial environments. As a result, the prerequisites are formed for reducing material losses at the sorting stages, reducing primary resource consumption and reducing indirect emissions due to improving the quality of secondary raw material flows.

The limitations of the study are related to the domain specificity of the data corpus and the range of shooting conditions. Despite careful control of lighting and exposure, possible changes in texture and color due to different fabric conditions in real flows require further expansion of the sample due to samples with increased variability in weave, fiber thickness and surface treatments. The subject of a separate analysis should be the influence of augmentation combinations on the behavior of the model for narrow subspaces of features related to the foldability of the fabric and the anisotropy of fiber orientations. It seems advisable to supplement visible-spectral microscopy with near-IR methods in future work, provided that the comparability of protocols and open access to new corpora are maintained.

The conclusions summarize that microscopic images in the visible spectrum in combination with a unified training, learning and evaluation protocol form a reproducible basis for neural network classification of textiles by fiber nature. The open sample corpus, standardized configuration and correct comparison of architectures ensure consistent achievement of high validation scores and demonstrate the practical readiness of the approach for integration into production and laboratory sorting processes, which supports the goals of a circular economy and resource conservation. Development prospects are related to corpus scaling, multi-scale feature representation, and domain-specific benchmarking protocols, which will enable further growth in the stability of metrics in complex scenes and expand the scope of application from quality inspection to full-fledged industrial sorting systems.

References

1. Sikka M. P. Artificial intelligence (AI) in textile industry operational modernization / M. P. Sikka, A. Sarkar, S. Garg // Research Journal of Textile and Apparel. – 2024. – Vol. 28, №1. – P. 67–83.

2. Liu R. The improved method in fabric image classification using convolutional neural network / R. Liu, Z. Yu, Q. Fan, Q. Sun, Z. Jiang // Multimedia Tools and Applications. – 2024. – Vol. 83, №3. – P. 6909–6924.

3. Molchanova M. Method for Construction and Demolition Waste Classification Using Two-Factor Neural Network Image Analysis / M. Molchanova, V. Didur, O. Mazurets, O. Sobko, O. Zakharkevich // CEUR Workshop Proceedings. – 2025. – Vol. 3970. – P. 168–182.

4. Dydo R. Analysis of Precision of Finding the Destroyed Remains Buildings on Photos using MobileNetV3 and ViT Neural Networks / R. Dydo, O. Sobko, M. Molchanova, O. Mazurets // Science and Technology: New Horizons of Development: Proceedings I International Scientific and Practical Conference, 14–16 May 2025. – Prague, Czech Republic. – P. 208–214.

5. Islam K. Recent advances in vision transformer: A survey and outlook of recent work / K. Islam // arXiv preprint arXiv:2203.01536. – 2022.

6. Dydo R. Analysis of Precision of Finding the Destroyed Remains Buildings on Photos using MobileNetV3 and ViT Neural Networks / R. Dydo, O. Sobko, M. Molchanova, O. Mazurets // Science and Technology: New Horizons of

Development: Proceedings I International Scientific and Practical Conference, 14–16 May 2025. – Prague, Czech Republic. – P. 208–214.

7. Kansal K. ResNet-50 vs. EfficientNet-B0: multi-centric classification of various lung abnormalities using deep learning / K. Kansal, T. B. Chandra, A. Singh // Procedia Computer Science. – 2024. – Vol. 235. – P. 70–80.

8. Xia J. An Efficient Medical Image Classification Method Based on a Lightweight Improved ConvNeXt-Tiny Architecture / J. Xia, Y. Yin, X. Li // arXiv preprint arXiv:2508.11532. – 2025.

9. Hladun O. V. Effectiveness research of using ViT neural network architecture for classifying the destroyed buildings remains / O. V. Hladun, M. O. Molchanova, O. O. Zalutska, O. V. Mazurets // Achievements of Science and Applied Research: Proceedings of 2nd International Scientific and Theoretical Conference, 19–21 May 2025. – Dublin, Ireland. – P. 96–100.

10. Dydo R. Datalogic structure for intelligent system for areas localization in photos with the remains of buildings using neural network / R. Dydo, O. Sobko, V. Klimenko, O. Mazurets // Modern Scientific Research: Theoretical and Practical Aspects: Proceedings II International Scientific and Practical Conference, 26–28 May 2025. – Riga, Latvia. – P. 123–127.

11. Sobko O. Method for analysis and formation of representative text datasets / O. Sobko, O. Mazurets, M. Molchanova, I. Krak, O. Barmak // CEUR Workshop Proceedings. – 2025. – Vol. 3899. – P. 84–98.