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

SEGMENTATION OF TEXTILE PRINTS WITH CONTOUR-STABLE COLOR MASKS FOR INDUSTRIAL STENCIL PRINTING USING ARTIFICIAL INTELLIGENCE

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The relevance of the study is due to the need to improve the technological controllability of color separation processes in textile production, where the quality of masks directly determines the accuracy of layer alignment, the stability of the boundaries between colors, and the proportion of defects on printing lines. In the practice of screen printing, small segmentation defects - contour breaks, blurred edges, serrations, and parasitic "islands" - accumulate during the preparation of the cliché and manifest themselves as paint leakage, line breaks, and uncontrolled overlaps in areas of fine details [1]. Standard approaches to the segmentation of textured surfaces are sensitive to inhomogeneous lighting, glare, local shadows, and slight deformations of the canvas, and their integration into industrial conveyors is complicated by the insufficient reproducibility of procedures and the lack of clear criteria for assessing contour stability [2]. This creates a scientific and practical demand for a methodology that focuses on the contour properties of the mask and harmonizes algorithmic solutions with the technological requirements of screen printing.

The aim of the work is to substantiate and experimentally verify a neural network approach to the segmentation of textile prints, focused on obtaining contour-stable binary or multi-class masks suitable for further color separation and printing plate production. Contour stability is understood as the invariance of the geometry of the boundaries to moderate changes in shooting conditions [3], as well as to permissible variations in prepress procedures for scaling the image to the size of the product [4], light affine transformations for alignment and local contrast corrections [5]. The subject matter involves working with fabrics and prints of different textures, where flat and ribbed areas, small strokes, gradient transitions and repeating micropatterns coexist, and a dual goal is also taken into account: on the one hand, maximum correctness of the boundaries, on the other hand, technological consistency of the masks with the subsequent stages of color separation and cliché preparation.

The proposed solution scheme treats segmentation not as an isolated module, but as the core of a reproducible training pipeline. Input images are normalized for illumination and color balance with minimal interference, which preserves textural features important for distinguishing the boundaries between color zones [6]. Augmentations are applied in a moderate intensity mode to simulate the operational conditions of the shooting without destroying fine details; small rotations, horizontal reflections and slight exposure shifts are appropriate [7]. The neural network segmentation module is chosen taking into account the trade-off between local accuracy and global consistency of the regions. Models with skip connections and multi-scale feature transfer paths ensure the preservation of fine structures, and the use of hybrid losses with a boundary-sensitive component reduces the risk of contour blurring. At the training stage, the emphasis is shifted from maximizing pixel accuracy to a balance between the planar integrity of the segments and the quality of the boundary line, which is more important from the point of view of printing technology. The Segment Anything Model (SAM) [8] was used as the basic segmentation model, which provides stable contour extraction under moderate variations in lighting and scene geometry without changing the overall structure of the pipeline.

Before the post-processing stage, a relevant mask is selected using a classifier that cuts off irrelevant SAM segments in complex scenes and guarantees the correctness of subsequent color separation. After inference by the neural network module, the masks undergo minimalist post-processing aimed not at cosmetic “smoothing” but at topological correction for printing suitability [9]. Local morphological operators are applied with adaptive radii tied to the optical thickness of the stroke in the original; this allows eliminating micro-gaps without changing the position of the boundaries. Edge maps calculated by an independent detector are used as a regularization signal to correct “edges” where the neural network solution loses subpixel accuracy. For complex areas with periodic patterns, local contour straightening in a curvilinear coordinate system is provided, which minimizes small sawtooth defects characteristic of voxel representation.

The key difference of the proposed approach is the introduction of evaluation metrics that directly represent production utility. Along with the usual planar indicators, the accuracy of the boundary in a narrow zone around the true contour and the consistency of the contours during repeated passes with different shooting conditions are considered. Such metrics are more sensitive to defects that actually appear on the form and print: sticking of thin gaps, divergence of contours at the junctions of layers and parasitic overlays during double-sided printing. The proposed evaluation system allows selecting model and post-processing configurations that provide the best compromise between topological integrity and contour stability, without pursuing the formal maximization of planar metrics at the cost of boundary deterioration.

Algorithmic details are consistent with the requirements of color separation. Masks must be geometrically compatible with the palette and with the expected number of layers, which are further formed by clustering or expert color separation. Contour stability in segmentation allows you to reduce the "swelling" or "drying" of ink spots when transferring a bitmap image to vector trajectories of the cliché, which directly reduces the risk of halos at the junction of layers. Consistency of boundaries at the pixel level facilitates the introduction of technological tolerances, such as squeegee pressure compensation, and reduces the width of the necessary safety overlaps between adjacent layers. In practical terms, this means less ink consumption, reduced cliché proofing time and a lower rejection rate in serial printing.

Special attention is paid to reproducibility. Model configurations, training parameters, normalization and post-processing rules are fixed in a single package that accompanies each test. Subsampling is performed in such a way as to prevent leakage of scene doublets between the training and validation sets. This is critical for an honest measurement of contour stability, since repeated motifs and twin samples in the opposite case overestimate the generalization ability. To assess portability, the "shooting with different lighting and different angle" mode is considered, where the preservation of the boundary geometry with a constant palette is checked.

The experimental design is focused on the analysis of complex cases. Test subsamples are formed taking into account thin strokes, small negatives, areas with gradient transitions and a high density of micropatterns. Fabrics with a relief texture are considered separately, where microshades can be mistakenly interpreted as boundaries of color zones. The proposed method demonstrates stable behavior in all specified modes: masks preserve the unity of the contour and the absence of parasitic "islands", and local corrections do not violate the global topology. Compared to the basic configurations that optimize only planar metrics, a more consistent combination of layers at the stage of further color separation and a lower need for manual refinement are noted, which confirms the relevance of the selected target criteria.

Practical integration into the industrial cycle involves exchange formats without loss of geometry. Masks are exported in vectorized form with a restriction on the minimum radius of curvature and with a guarantee of the absence of self-intersections, which reduces the risk of errors in the software for making clichés. Technological marks for registering layers are added at the prepress stage according to known templates, and their position is tied to the reference points of the masks. This ensures a consistent geometry transfer between the segmentation system, color separation schemes and press equipment, and also facilitates tracing the causes of defects in the event of deviations during printing. An example of segmentation is shown in Fig. 1.

From a resource saving perspective, the impact is manifested in several related dimensions. Improving the quality of the boundaries reduces the number of cliché attempts and re-runs, which reduces the consumption of energy, materials and personnel time. Reducing the width of the safety overlaps between layers reduces ink consumption without losing visual quality, and the absence of parasitic overlaps reduces the likelihood of batch rejections. Taken together, this supports circular economy approaches, as it reduces waste, increases repeatability of quality and makes supply chains in serial printing more stable.

The limitations of the work relate to the variability of fabrics and printing conditions. Textures with pronounced pile, metallized threads or local glare may require special lighting modes during shooting or separate normalization profiles. Gradient zones and smooth color transitions are not always unambiguously subject to binary segmentation; in such cases, soft masks are justified with subsequent thresholding controlled by the technological limitations of a particular paint and fabric. At the same time, the algorithmic scheme remains portable, since the key solutions target metrics on the boundary, topologically directed post-processing and vectorization requirements do not depend on the specific architecture of the model and can be adapted to other software and hardware platforms.

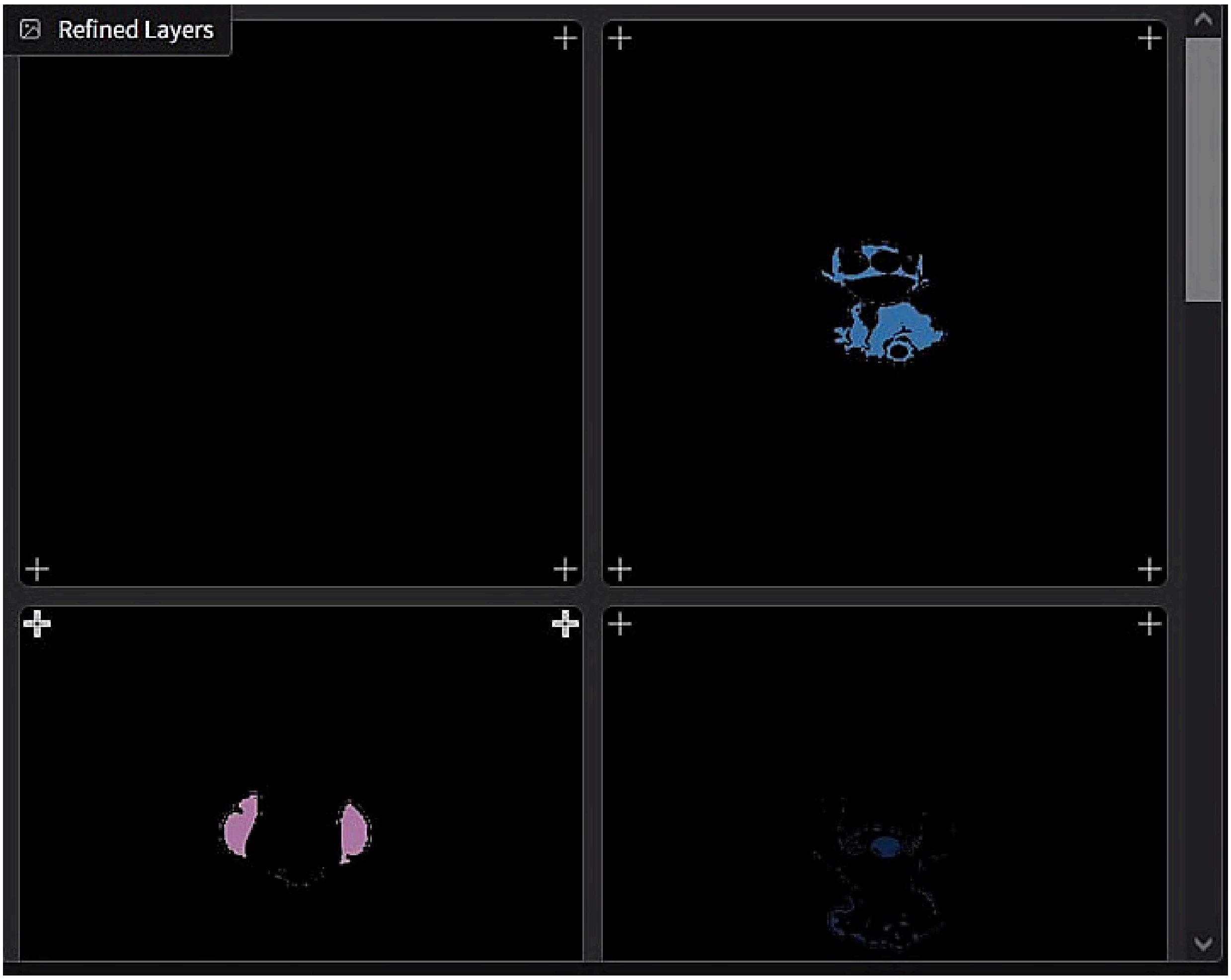

Fig. 1. Example of segmentation by the developed application

In summary, the proposed approach shifts the focus of segmentation from formal pixel accuracy to contour stability as a technical and technological goal directly relevant to industrial screen printing. The combination of neural network segmentation with minimalistic but topologically motivated post-processing, together with metrics reflecting the behavior of boundaries in production modes, forms a reproducible method for preparing masks for color separations. The practical effect is manifested in reducing prepress costs, reducing scrap and increasing the stability of layer alignment in serial runs. Further research is aimed at expanding the data corpora with complex textures, improving local boundary correction rules for specific fabrics and formalizing evaluation protocols that take into account the full cycle from digital mask to control print on the product.

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