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ALGORITHMIC SCALING OF TEXTILE PRINTS FOR SERIAL MULTICOLOR PRINTING WITH PALETTE REPRODUCTION USING NEURAL NETWORKS

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The relevance of the study is due to the need to ensure the reproducibility of the appearance of multilayer textile prints when moving from single mockups to serial production with different physical product formats. In the practice of screen and combined printing, scaling of the print is often accompanied by degradation of contours, displacement of fine details and undesirable changes in the palette, which leads to an increase in the proportion of defects and repeated runs [1]. Simple geometric transformations of the image in pixel space do not take into account the technological limitations of the printing process, the influence of fabric texture and the nature of the application of paint layers, which leads to artifacts such as sawtooth borders, halos at the junctions of colors and migration of contours in the areas of small elements [2]. At the same time, serial orders require the print to be scaled simultaneously for several sizes and media, while maintaining the geometry of the contours and the stability of the color layers throughout the batch. This forms a scientific and practical demand for an algorithmic scaling method in which geometric transformation, spatial resolution update, interlayer matching, and palette reproducibility are considered as a single coordinated process.

The aim of the work is to substantiate and experimentally verify an algorithmic scheme for scaling textile prints for multi-color serial printing, which ensures contour invariance and palette reproducibility when changing the physical size of the product and preparation parameters. Invariance is understood as the preservation of the metric properties of the boundaries and topological integrity of the masks for each color layer, and reproducibility is the stability of the color relations and optical density of the layers between instances within the series. The central element is a neural network module for increasing spatial resolution, which performs contour-consistent upscaling without changing the shape of the boundaries and without the appearance of false high-frequency details [3]. The second pillar of the method is controlled color rescaling, which preserves the palette and hierarchy of layers when changing the scale, taking into account the media material and the features of the application of paints.

The initial prerequisite is the availability of high-quality binary or multi-class masks suitable for color separation. Scaling begins with the construction of a mapping between the artistic coordinates of the print and the physical coordinates of the product, where only isotropic transformations are used with control of permissible deformations. At this stage, the issue of compliance of the resolution of the digital layout and the expected optical thickness of the stroke on the fabric is resolved. If the target format requires an increase in pixel density, neural network upscaling is resorted to, which is trained on samples of printing contours printed in real conditions. Such training sets the module the priority of contour geometry over textural “invention”, due to which thin boundaries are preserved without ripples and steps. For areas with regular micropatterns, a locally adaptive mode is used, where spatial frequencies are restored taking into account the repetition of the motif, which reduces the risk of moire artifacts appearing in the raster.

Geometric consistency between color layers is maintained by jointly transforming the masks in a single deformation field. This avoids cumulative errors when scaling layers separately and preserves the original distances between adjacent color boundaries, which are critical for preventing overlaps. Vectorization of contours before transformation ensures preservation of curvature and minimization of local kinks, and subsequent repixelation is performed with antialiasing controlled by the minimum optical stroke thickness metric. For large formats with memory constraints, tiling with overlap and subsequent seamless gluing along lines where the gradient of contour curvature is minimal is used; this eliminates possible shifts at tile joints, noticeable on thin elements.

The color block is oriented so that scaling does not change the hierarchy and perception of the palette. In the simplest case, the palette is given by a stable technological table of colors for each layer, but in real conditions, changing the scale requires corrections of optical density due to changes in the spatial frequency of details. The neural network color matching module performs regression from the local fragment of the print to the parameters of the ink control, bringing the measured color closer to the target in the perception space. The training is carried out on the pair "digital color measured print" with control of the influence of the fabric, squeegee pressure and the sequence of applying layers. This achieves the stability of shades in areas of fine raster, where optical mixing would otherwise cause noticeable shifts. The module does not change the artistic idea or redefine color classes; its role is to coordinate the application parameters so that the digital palette is reproduced the same for different scales and runs.

Production reproducibility is measured at the level of series, not individual prints. Therefore, the evaluation includes repeated runs with independent preparation, where variations in the geometry of the contours in the micron range are recorded by reference marks and color changes by spectrophotometric indicators. Spatial compliance is controlled at reference nodes located at the intersection of dominant contours, which allows to assess both drift and local deformations. Color compliance is analyzed for individual layers and for the composition, since it is the interaction of the layers that creates the final perception. In cases with a large number of small details, it has been noted that neural network correction of optical density reduces the inter-run spread of perceived color, especially in midtones, where small deviations in application are most noticeable.

Algorithmic solutions are closely related to resource conservation issues [4]. Correct geometric transformation without loss of contours shortens the cliché proofing cycle, as it reduces the number of manual edits and re-exposures. Palette stabilization reduces the number of batch rework, especially for orders where one print is applied to different sizes of products or materials. As a result, ink and substrate consumption is reduced, energy consumption in preparatory processes is reduced, and the load on the supply chain is reduced. At the same time, color reproducibility facilitates integration with responsible consumption practices, as it allows for predictive management of ink stocks and minimizes write-offs due to shade mismatches.

Particular attention is paid to data and configuration requirements, since it is the discipline of the process that guarantees the comparability of results [5]. Upscale parameters, compensation fields, tile repeatability settings, color correction profiles, and model versions are fixed for each scale. The division into series is formed in such a way as to assess the portability between batches, for which the tests include changes in the carrier with similar, but not identical textures and changes in standard application conditions. In such modes, the scheme demonstrates the maintenance of geometric accuracy of the contours within the limits of manufacturing tolerances and the stability of the palette, sufficient for a visually indistinguishable result in repeated runs. The proposed technique does not impose a specific architecture of neural network blocks [6] and can be implemented on different platforms [7] provided that the principles are observed. The first principle is the priority of contour geometry when increasing the resolution; any model that ignores boundaries will generate unwanted high-frequency artifacts. The second principle is the joint transformation of all layers in a single deformation field, which guarantees alignment without accumulating errors. The third is the separation of artistic and technological levels, where neural network palette correction is consistent with the measured print and does not change the layer classes. Adherence to these principles allows the solution to be adapted to other printing technologies and to materials with different optical properties.

The limitations of the work are associated with extreme scales and particularly complex textures. Very large magnification factors require additional training of upscale models on examples with similar spatial frequencies, otherwise there is a risk of excessive smoothing of thin elements. Fabrics with pronounced pile or metallized fibers change local scattering, which affects the perceived color after scaling; in these cases, it is advisable to strengthen color correction with local profiles and additional calibration {Fig. 1). For prints with gradient transitions, combined masks with soft boundaries are used, but technological requirements may limit the degree of softness; coordination of these limitations requires separate experiments on target media.

In general, algorithmic scaling of textile printing is considered as an integrated task that combines geometric invariance of contours, restoration of spatial resolution and stabilization of palette in conditions of serial multi-color printing. Neural network upscaling [8], trained with the priority of contour geometry, in combination with joint transformation of layers and controlled color re-adjustment forms a reproducible process in which the scale does not degrade the quality of boundaries and does not change the perceived color relationships.

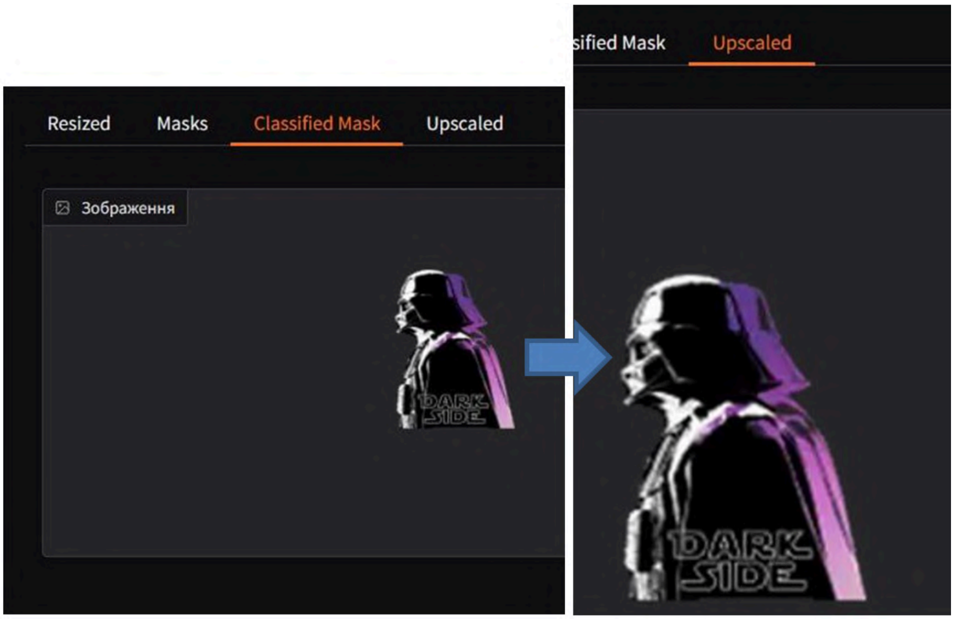

Fig. 1. Example of scaling by the developed software application

The practical effect is manifested in the reduction of prepress cycles, reduction of the percentage of defects and stabilization of quality within and between batches, which directly corresponds to the tasks of resource conservation and supports circular economy approaches in textile production. Further work should be directed towards expanding the training corpus for upscale with the inclusion of control prints for different media, formalizing protocols for serial reproducibility assessment, and integrating online spectrophotometric feedback for automatic palette correction during replication.

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