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AUTOMATION OF TEMPLATE CORRECTION ALGORITHM FOR QUALITY IMPROVEMENT OF PSEUDO-3D ENGRAVED IMAGES

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ABSTRACT

The method of correcting templates of pseudo-3D images engraved on wood and wooden materials is proposed. The key elements of the method comprise initial engraving of the test model with an optic density gradient, measurement followed by further analysis of the engraving optical density, finding the threshold values of the workpiece material tone, and correction of the image output values. The algorithm is composed, and the variant for automating the template design is proposed. A more complete reproduction of light-and-dark gradations of the image engraved is achieved in the material, and the template design is accelerated and simplified. The experiments confirming the efficiency of the proposed approach were carried out.

Keywords: laser engraving; wood; half-tone wedge; template correction; tone range.

INTRODUCTION

Laser radiation is successfully applied in processing wood and wooden materials – surface ablation (Makarov *et al.,* 2011), biological protection (Parfenov *et al.*, 2011, Vidholdova *et al.,* 2017), cutting (Hernandez-Castaneda *et al.*, 2011, Eltavani *et al.*, 2013, Martinez-Conde *et al.,* 2017), marking and engraving (Gorny et al., 2009, Kubovsky *et al.,* 2016, Geffert *et al.,* 2017). Laser engraving allows researchers to create complex images on wood and wooden materials (Chernykh *et al.*, 2018, Gochev *et al.*, 2018) of high aesthetic value, decorate products with ornament (Chernykh *et al.,* 2012, Lungu *et al.*, 2022, Kumpan *et al.,* 2015), improve functional and decorative properties of products' surface (Petuchnig *et al.,* 2013), control processing quality.

It is most difficult to achieve high quality products when engraving pseudo-3D images, since the aesthetic value and faximility of products depend not only on processing quality but also on the reflection degree of light-and-dark gradations of the original in the product (photograph, drawing). In the work (Zykova *et al.*, 2022) the following technologically controlled components of the aesthetic value and faximility of the engraved images were pointed out: contrast, detailing and perception integrity of the image.

The contrast is defined by the processed wood tone ratio to its natural tone. The most contrast achieved on the wood of a certain species is bound by the tone limit of this species, and when it is reached, the further laser radiation power increase does not result in a darker tone and improved contrast due to the wood carbonization (Yakimovich *et al.,* 2016).

Tone limits of different wood species have different values (Chernykh and Yapparova, 2012). In some works (Chernykhand Yapparova, 2012, Yakimovich *et al.,* 2016), it is proposed to evaluate the wood tone limit as the black color percentage in CMYK based on the sample scans as a half-tone wedge using Photoshop tools. CMYK model is subtractive: every color in it is formed by the subtractionof any color from the white one (Color models…https://clcr.ru/34wiGf). The model's name corresponds to the first three letters in its main colors – Cyan, Magenta, Yellow – and the last letter in the black color – blacK. Black color in the model allows comparing the tone contrast and intensity (frequently of a black-and-white photograph), computer original, template and image engraved on wood.

However, scanning produces an error in an image tone. To improve the quality of engraved images and preserve faximility, it is necessary to use the material tone range to full extent, due to the direct tone measurement on the material being engraved.

Another aesthetic value index – detailing – is defined by the size of minimally distinct image engraving elements and can be estimated visually by applying expert assessment method following the technique discussed in the paper (Chernykh *et al.,* 2013).

The third index – image perception integrity is also estimated visually. This index is defined by the reproduction degree of the original light-and-dark gradations in the engraved image. Light-and-dark gradations allow the perception of an image on a flat surface as volumetric and integral.

In practice, the original light-and-dark gradations (photograph, drawing, etc.) are reproduced experimentally due to the selection of power and engraving speed. Such a method requires a large amount of experiments and samples. Other methods providing a 3D perception of engraved images are not sufficiently discussed in the literature.

MATERIALS AND METHODS

The investigated tree species – birch wood.

Samples:
- 1-mm-thick veneer sheet glued onto MDF base,
- 5-mm-thick plywood,
- 15-mm-thick wood board,

Samples moisture content: 12%.

Equipment:
Laser CO_2 marker with CNC GCC Synrad (USA), 30 W (Fig. 1).

The engraving power was 4.5 W, the speed – 1000 mm/sec, focal distance – 300 mm, the focal plane position coincided with the surface engraved.

Fig. 1 Laser engraving equipment.

Engraving of uncorrected template

To complete the formulated tasks, we engraved the test image, for which the half-tone wedge (Fig. 2), (GOST 24930-81) with black color intensity gradient within 0-100% was used. The use of high contrast standards, e.g., 167A2 – 1996 – IEEE Standard Facsimile Test Chart: High Contrast (GrayScale) or GOST 28267-89 half-tone raster wedge as test models does not result in contrast enhancement of the engraved model, improved accuracy in finding threshold values of the workpiece material tone. This relates to the blurred laser beam trace on the wood surface due to its properties, wood natural tone and tone limit. It is possible to obtain only the contrast average value during the laser engraving on wood.

Fig. 2 Half-tone wedge (GOST 24930-81).

The image was engraved along and across the fibers on several test samples (Fig. 3) of birch wood, including: plywood, board and veneer sheet. Engraving parameters: resolution 600 dpi, power P = 30 W, frequency 20 kHz.

a

b

c

d

e

f

Fig. 3 Engraved half-tone wedge image on birch wood: a – plywood along the fibers, b – plywood across the fibers, c, d – boards along the fibers with different tone values, e – veneer sheet along the fibers, f – veneer sheet across the fibers. Sizes of the samples 17×125 mm.

The values of optic density D of the half-tone wedge engraved image steps on all tested samples were measured using the the densitometer by "KLIMSCH" (Germany) demonstrated in Fig. 4.

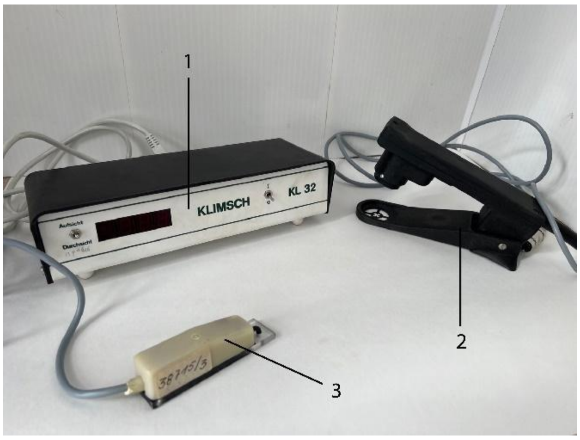


Fig. 4 Densitometer and its components: 1) measuring device, 2) light source, 3) receiver.

The receiver was not used in the work since the measurements were made on reflection, not transmission. The result was immediately displayed on the screen without additional mathematical operations. The light source was placed above the measuring region and the result was displayed on the measuring device screen afterwards.

RESULTS AND DISCUSSION

Engraving on uncorrected wedge template

The measurement results are given in the value graphs (Fig. 5) and Tab. 1. The common regularity within one workpiece, the stability of optical density values of the first steps and decrease after the maximum is observed.

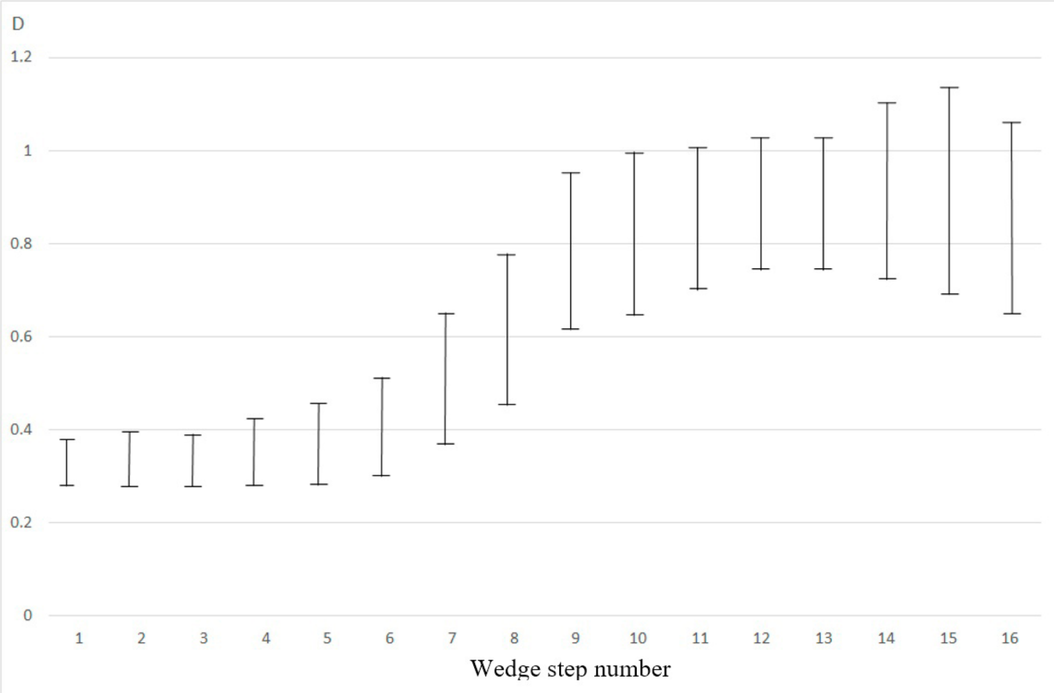


Fig. 5 Results of measuring optical density D of the engraving on different samples with resolution R=600 dpi.

Tab. 1 Results of measuring optical density D of the engraving on different samples.

Half-tone wedge step number	Sample number					
	I	II	III	IV	V	VI
1	0.33	0.34	0.41	0.36	0.32	0.32
2	0.33	0.34	0.42	0.36	0.32	0.32
3	0.33	0.34	0.42	0.36	0.32	0.34
4	0.37	0.34	0.45	0.36	0.32	0.34
5	0.37	0.38	0.48	0.38	0.32	0.41
6	0.40	0.45	0.53	0.43	0.34	0.47
7	0.48	0.50	0.66	0.49	0.40	0.63
8	0.60	0.57	0.78	0.62	0.48	0.67
9	0.68	0.64	0.94	0.70	0.63	0.78
10	0.77	0.64	0.98	0.74	0.73	0.74
11	0.81	0.71	0.99	0.88	0.82	0.81
12	0.89	0.75	1.01	0.88	0.85	0.87
13	0.91	0.75	1.01	0.92	0.90	0.81
14	0.94	0.73	1.08	0.96	0.95	0.84
15	0.90	0.70	1.11	0.94	0.93	0.82
16	0.82	0.66	1.04	0.85	0.73	0.82

Note: I – plywood along the fibers; II – plywood across the fibers; III – board along the fibers; IV – board lighter in tone along the fibers; V – veneer sheet along the fibers; VI – veneer sheet across the fibers.

From the presented measurements, it is seen that the preservation of the initial tone range (template black color intensity within 0-100%) when engraving the image results in the merge of the light spots similar in tone (steps 1-5 of the wedge) making them alike. A similar problem occurs in the region of dark spots (steps 14-16 of the wedge). As a result, light-and-dark gradations of pseudo-3D original are not reproduced in the light and dark regions of the engraved product that deteriorates the image quality, namely, faximility and aesthetic value.

Wedge template correction

It is possible to avoid the incorrect image transfer by changing the output values of the initial template, narrowing its tone range. To reach this goal, the algorithm developed based on the research results conducted on the samples of birch veneer sheet with the engraving across the fibers was proposed. The selection was conditioned by the fact that the heat flow spreads slower across the fibers and tone gradations are reproduced in a smoother form in comparison with the engraving across the fibers (Chernykh, 2014).

1. The half-tone wedge image was made on the test sample with the help of laser engraving (see Fig. 3).

2. The optic density of each step of the engraved template was measured by the densitometer.

3. The graph of the engraved template optic density values was plotted for visualization and data overview (Fig. 6).

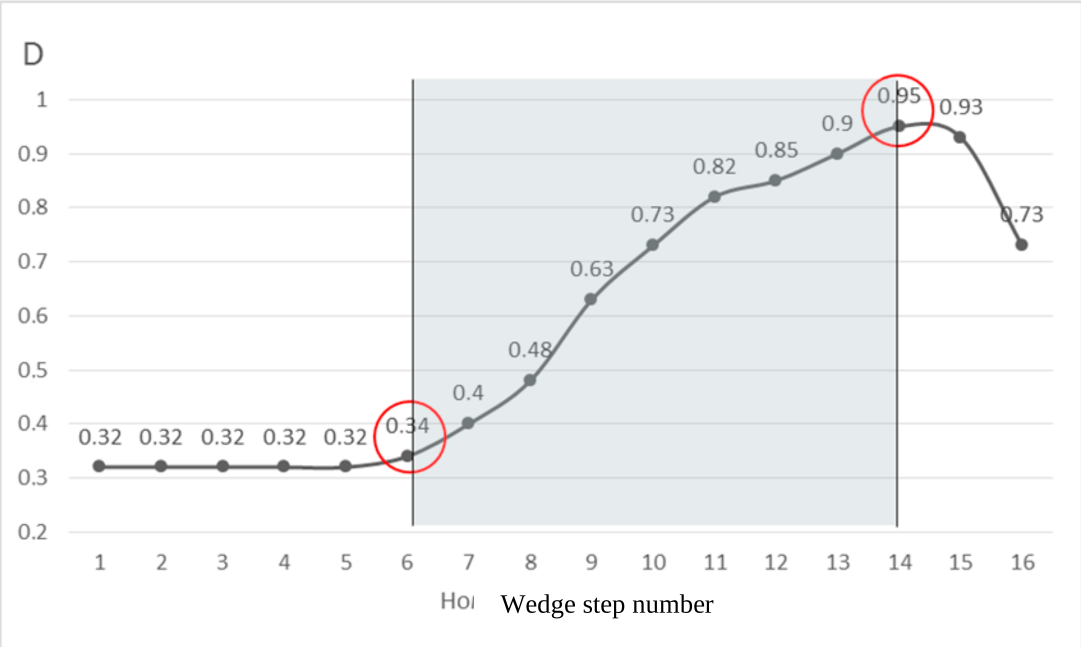


Fig. 6 Results of measuring optical density of the engraving across the fibers on birch veneer sheet with resolution R=600 dpi.

4. In the graph, the first optic density value different from the workpiece optic density (step 6) corresponds to the maximum brightness value, which can be obtained by laser engraving on the selected workpiece.

5. The maximum numerical value of the optic density, followed by its decrease, corresponds to the minimum brightness value obtained by laser engraving (see Fig. 7).

6. The steps corresponding to the optic density maximum and minimum values are marked in Adobe Photoshop on the test strip original (see Fig. 2).

7. The bit value, i.e., the brightness value of the limits found, is marked as the rangeupper and lower tone thresholds (upper and lower tone thresholds of the range) (Fig. 8).

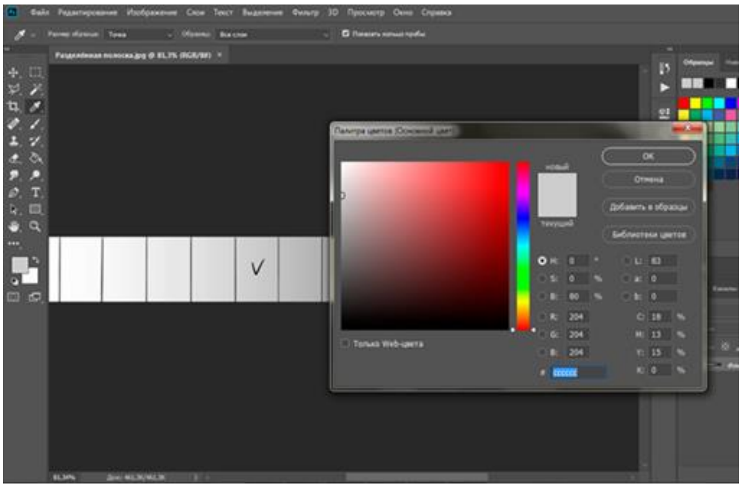


Fig. 7 Bit value of the brightness limits.

8. In the graphic editor, e.g., Adobe Photoshop, the tab “Image – Correction – Levels” is opened through the main menu where the maximum and minimum values obtained on the half-tone wedge are entered in the window of output values of the engraved and pseudo-3D images. All light-and-dark gradations of the original can be reproduced on the workpiece only in this case, eliminating possible losses in the regions of light and dark tones.

The control check performed during the half-tone wedge laser engraving (Fig. 8) demonstrated that the engraved sample optic density increased proportionally to the wedge template optic density increase (Fig. 9). Slight deviations from the proportional dependence were connected with the texture influence.

a

b

Fig. 8 The half-tone wedge: a – corrected template of the test strip, b – engraving of the test strip made on the birch veneer sheet based on the corrected template (17×125 mm).

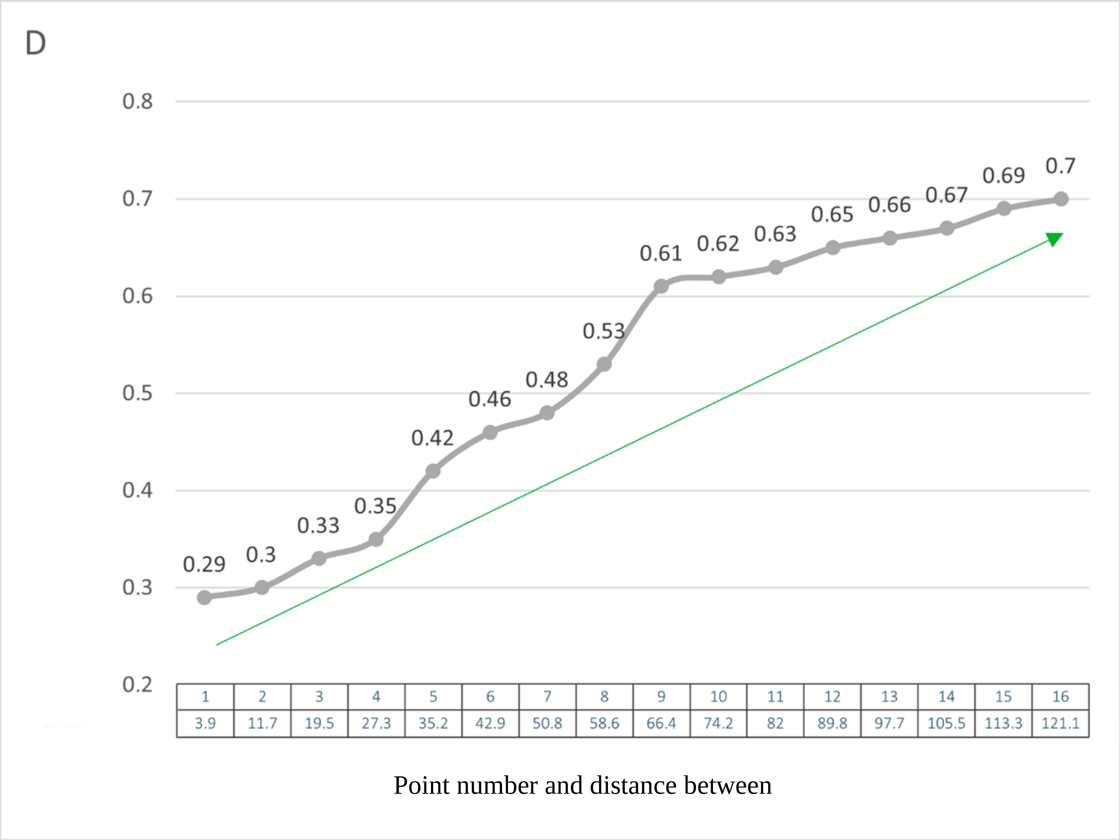
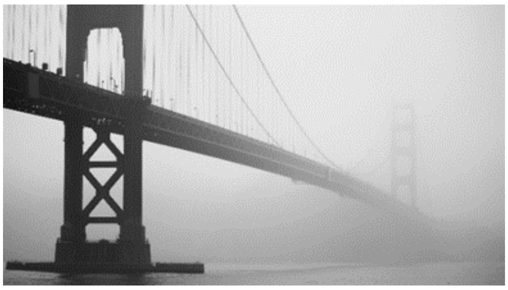


Fig. 9 Graph of the engraving optic density values plotted based on the corrected half-tone wedge template.

Thus, the output threshold values of the tone range boundaries identified by the engraver were obtained. They can help in correcting any image before applying it to wood by laser engraving.

Engraving of pseudo-3D images

The tone images were engraved with and without the template correction for comparison. Resolution R was 1000 dpi (Fig. 10).



a

b

c

Fig. 10 Original (a) and engravings on the birch veneer sheet: without the template correction (b), with the template correction (c), (78×130 mm).

During the visual examination, it is seen that some elements, similar in tone, and the fog blend in tone with the workpiece on the uncorrected engraving “b”, and on the engraving “c” we can see the distant tower hidden by the fog and descending vertical wire ropes are also distinctive, but on the engraving “b” these elements and the fog blend in tone with the workpiece.

12 dots, in which the optic density was measured, were singled out on each of the engravings “b” and “c” for more precise evaluation (Fig. 11). The optic density of the image of the same format as the engraving printed on a white paper was measured for comparison. The horizontal and vertical dimensions of the image in millimeters are shown along the coordinate axes.

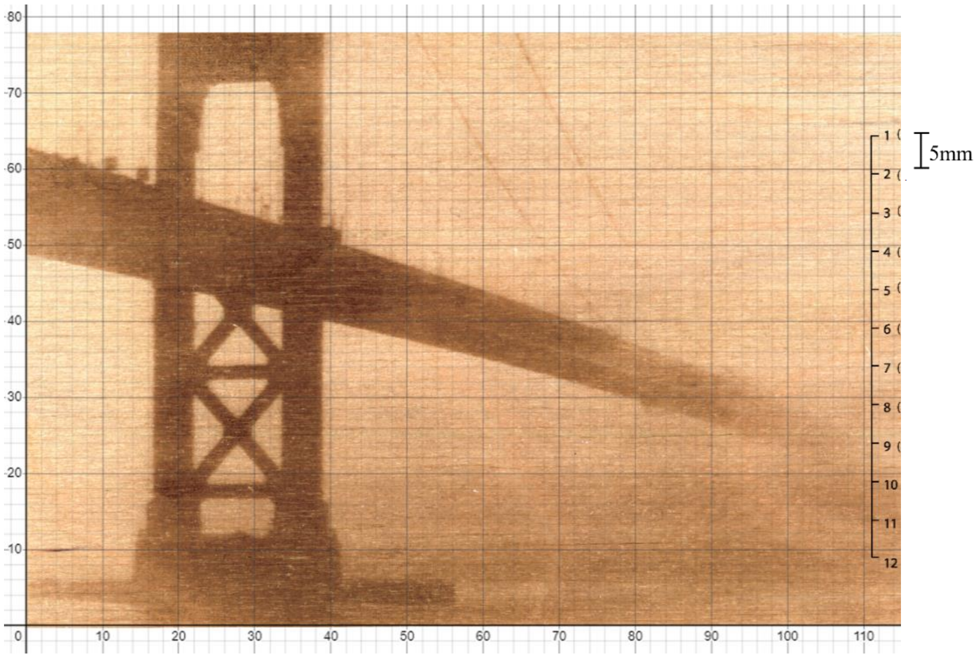


Fig. 11 Optic density measurement region.

The results of optic density measurement and comparison of tone gradations are demonstrated in Fig. 12.

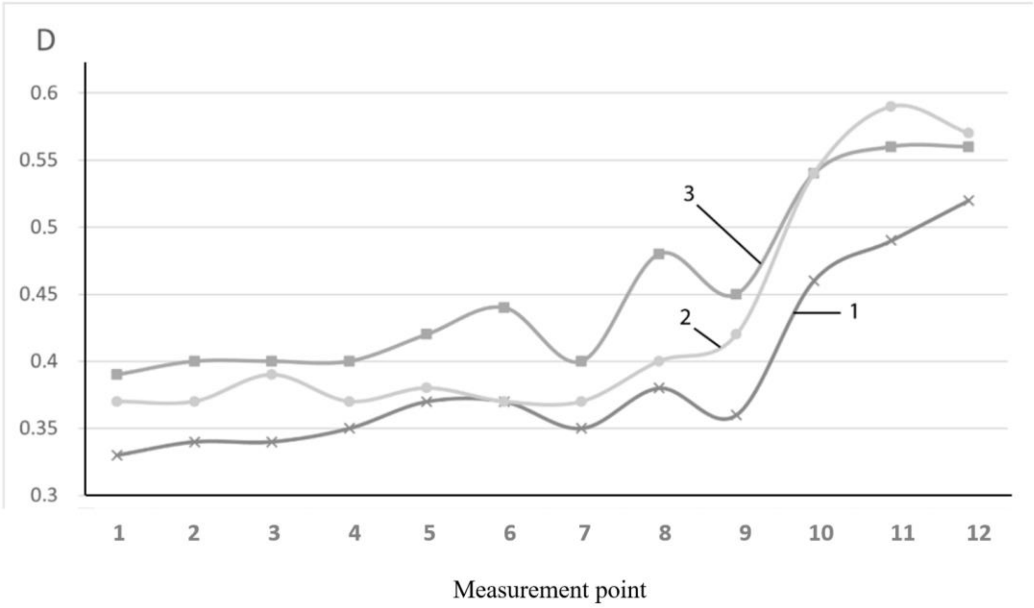


Fig. 12 Optic density measurement results: 1 – original; 2 – engraving without the template correction; 3 – engraving with the template correction. The distance between points is 5 mm.

It should be pointed out that the ups and downs of the graphical dependencies obtained related to light-and-dark gradations of the images – the tone is darker on the graph vertexes and lighter in the hollows.

Comparing the graphs, we should specify that line 3 is almost parallel to line 1, which indicates that the amount and location of light-and-dark gradations of the engraving based on the corrected template (line 3) correspond to the original (line 1). The original faximility and image 3-dimensionality are reproduced on this engraving. And on the engraving produced based on the uncorrected template (line 2) a part of tone gradations is lost that is especially visible in the region of light tones corresponding to dots 1-7 in Figure 11. The light-and-dark gradations are poorly expressed in the region between dots 1 and 7 and can be invisible. The instrumental analysis results confirm the conclusions of the visual evaluation presented above. Thus, the template correction allows for improving the image engraving quality.

Based on the conducted research we composed the image correction algorithm (Fig. 13) and proposed the variant of the template correction process automation.

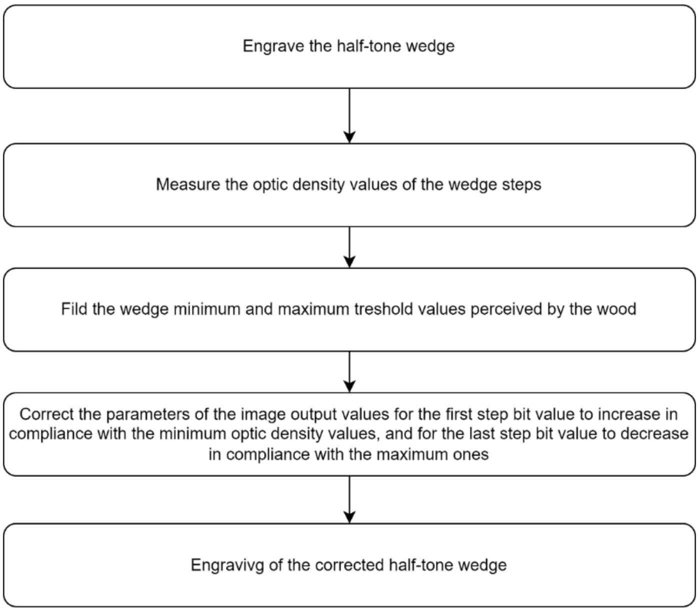


Fig. 13 Template correction algorithm.

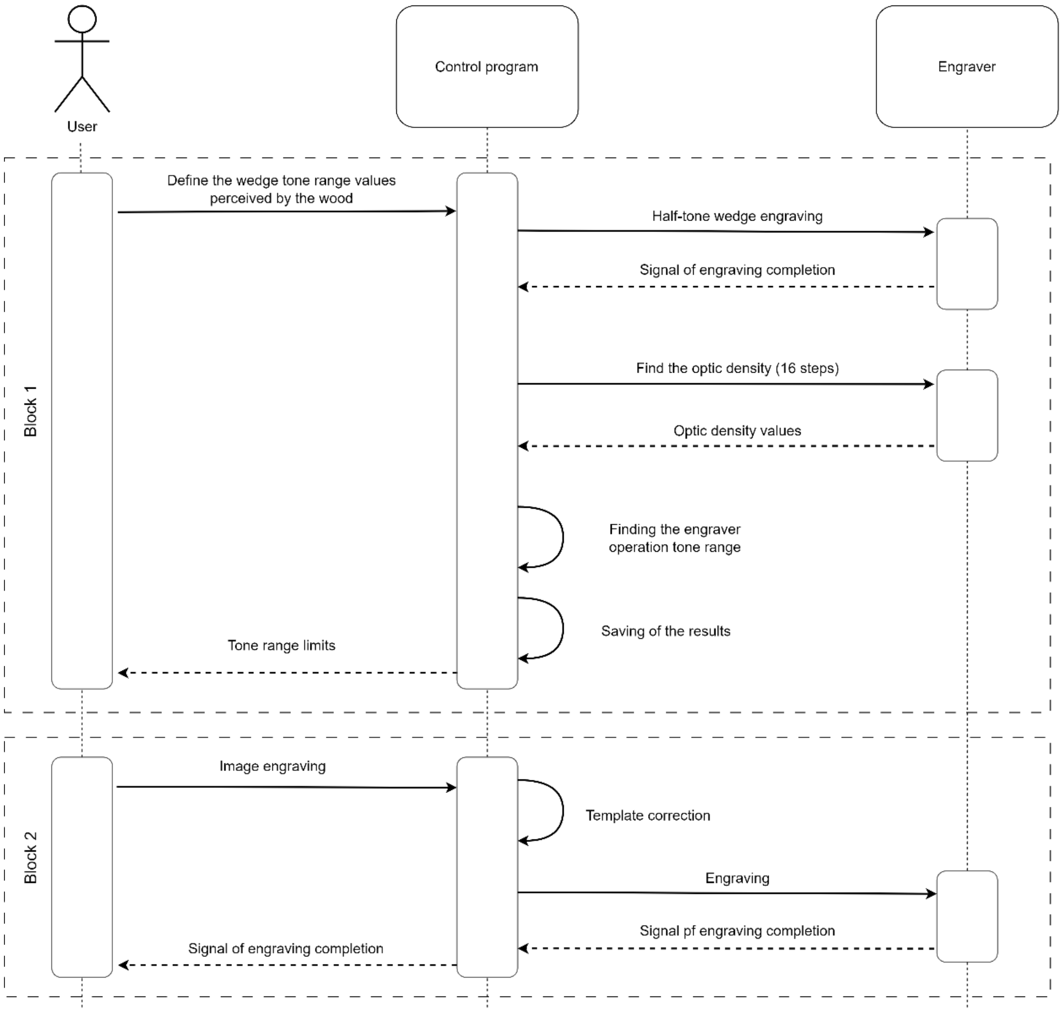


Fig. 14 Automated process model.

The image correction automated algorithm represents a scheme consisting of two blocks (Fig. 14). The first block describes the process of sending the user's request to the engraver to specify the tone range perceived by the wood. The engraver, with the help of the densitometer and control program installed, engraves the test image and finds the tone maximum and minimum values, which can be reproduced on the given species, and then the obtained data are returned to the user.

In the second block the user sends the image to be engraved, the engraver automatically corrects it in compliance with the data obtained from block 1 and sends the engraving of the corrected image back to the user.

Thus, the necessity to manually correct the template before engraving to preserve the image faximility and aesthetic value is eliminated.

CONCLUSION

The method of correcting pseudo-3D images consisting of measuring the optic density of the test model with the optic density gradient made on the material of the product to be engraved and correcting threshold values of the image template tone brightness following the optic density measurement results is proposed.

The method allows for improving the quality of the products engraved due to more complete and accurate reproduction of light-and-dark gradations and 3-dimensionality of the original image in the product.

Measurement of the optic density of images engraved on the birch wood veneer sheet demonstrated that the amount and location of light-and-dark gradations on the image made based on the corrected template correspond to the original, whereas a part of light-and-dark gradations is lost on the reference image produced based on the uncorrected template.

The developed template correction algorithm minimizes user involvement, creating prerequisites for automatizing correction and accelerating the engraving technological process.

The correction algorithm is applicable to any equipment for laser engraving; however, it is necessary to conduct an individual test for each engraver and workpiece to find threshold values of the workpiece material optical density. Using the half-tone wedge by GOST 24930-81 as a test model is practicable.

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