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Resolution of Achromatic Prints as a Predictor of Qualimetric Decision

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Abstract: - In this paper, a methodology for quantitative assessment of the quality of achromatic raster images on paper has been developed. Analysis of the relationship of subjective and objective quality indicators in the evaluation of printed images has been carried out. We found an analytical form of the dependence of perceived quality on the resolution of black-and-white raster images without compression printed on white paper by an inkjet method. Differential thresholds for two resolution ranges are defined. Directions for further research are indicated.

Key-Words: - Predictor, Resolution, Decision-making, Qualimetrics, Differential threshold

1 Introduction

The study of the dependence of subjectively perceived quality of printed images (prints) on their objective characteristics is of interest not only for printing (in particular, from the point of view of optimizing the cost of high-quality products producing), but also for understanding the fundamental principles by which a person takes qualimetric decision. Quality is a subjective category leaned on judgments based on an individual's internal assessment of their sensory experience. To date, there is practically no domestic scientific basis for assessing the perception of quality, and in this regard, one can rely only on expert assessments. Moreover, the instrumental methods of evaluation are also based on the patterns of human perception.

Formally, the quality of rints is determined by a set of standardized parameters that correspond to different standards from the field of printing art. On the other hand, the customer of printing industry evaluates the result primarily not on the technical parameters of the print, but rather, visually. The possibilities of visual evaluation are limited by such parameters as visual acuity and frequency-contrast characteristic [1]. If we talk about the reproduction of color, the point determining quality for the observer is psychological accuracy [2], both in the presence and in the absence of the original. This means that when viewing an image, the observer first check the reliability of the most important colors, such as corporal colors, where any extraneous shades are sharply noticeable and psychologically unacceptable. At the same time, most people do not pay attention to significant color distortions in the background or psychologically insignificant details of the image [3]. Like many other values, subjective perception of the printed images quality can be given accurate quantitative assessment by conducting psychophysical experiments that establish the relationship between physically measured stimuli and the sensations caused by them. To determine the relationship between objective and subjective quality, an experiment on psychometric scaling is required.

Fundamental works on psychophysics are the works of Weber, Fechner and Stevens. Weber at the beginning of the nineteenth century established that the ratio of the increment of the stimulus to its initial quantity is a constant value (Weber's law), and the unit of perception is the so-called just noticeable difference (JND). Fechner found a relationship between the intensity of the stimulus and the magnitude of perception. He transformed the intensity scale of the stimuli into a scale of perception values using a logarithmic transformation (Fechner's law). According to this law, which is valid for most modalities, the values of stimulus perception are proportional to the logarithm of its physical intensity.

Stevens suggested that the ratio under consideration does not follow the logarithmic Fechner function, but goes according to a power law with different coefficients for various modalities (Stevens' law) [4]. Thus, the reactions of sensory systems are monotonous nondecreasing functions of the intensity of the stimuli adequate to these systems.

The subject of print quality is presented mainly by international printing standards, as well as standards on the work with photographic materials. For example, in the family of standards ISO 20462 [5], [6], [7] general psychophysical methods for evaluating the quality of photographic images are described, irrespective of the technology for obtaining them. The technique used in the present work is in many respects similar to the approaches described in the above-mentioned standards, but it significantly expands the analytical possibilities. In literature, you can also find a number of works related to psychophysical studies of subjective perception of the quality of digital images [8], [9], as well as comparison of "full color" digital and offset prints [10]. However, they do not raise questions about the boundaries of indistinguishability of subjectively perceived quality of prints and, especially, differential thresholds.

The task of quantitative evaluation of image quality is complicated by the fact that it is difficult to find an effective measure of subjectively perceived distortions, and also because of the fundamental difference in physical and subjectively perceived distortions [11].

In [12] a variant of the method of objective analysis of prints was proposed. It also indicates that the calculated complex indicator that evaluates the performance of digital printing equipment from the point of view of the analysis of production, ergonomic, economic and other factors, being a numerical measure of testing equipment for the quality of the prints received, would be useful both for the owners of printers and for customers of printed matter . However, the author does not affect the subjective aspect of the perception of impressions.

Thus, there is a need to identify the relationship between the objective characteristics of the printed image and the subjectively perceived quality, and based on this, to conclude how to create printed products at a low cost that would satisfy the customer's requirements.

The aim of this work is to develop a technique for qualimetric measurements of achromatic images on paper, to construct the dependence of perceived quality on the resolution of the original file, and to develop recommendations for practical use.

2 Experimental

In total, 43 students of Ural Federal University, Yekaterinburg, Russia took part in the experiment.

The stimulus material was represented by achromatic raster images 100 × 100 mm on 7 topics, printed by ink-jet printing method with resolution of 4800x1440 dpi on a special white matte paper. In order to exclude the influence of the frequency component on the perception, the images were printed with a stochastic raster, which together with the high print resolution gave the "photographic" quality of the initial impressions. In order to exclude associated distortions when analyzing stimulus material by respondents, images were selected in such a way that their emotional and semantic load were minimal. Subjects are phenomena, people or objects that often occur in everyday life. The names of the themes and their images are shown in Fig.1 The source files in the RAW format were converted to TIFF format without compression in Adobe Lightroom. After that, in Adobe Photoshop, a fragment of 100 × 100 mm with a resolution of 204.8 × 204.8 pixels / cm was cut out from each image. This fragment served as a basis for subsequent reduction of resolution, performed with the command Image → Image Size. To obtain new, smaller resolution values, the interpolation method "by neighboring pixels" was used. As the tone of the new pixel, the average tone of its nearest actual neighbors is taken.

Fig.1 Stimulus material

Each photo was coded with a number from 1 to 15 and encrypted. The numbers were randomly generated, and in each series their sequence was different. The code was geometric, not numerical, so as not to cause respondents to assume that the prints were assigned serial numbers and did not distract their attention. A number of image resolutions in TIFF format are presented in Table 1. The series was chosen in such a way that qualitative changes in the photographs occurred gradually.

Table 1. Image Characteristics

«Own» rank	Image size, pixels		Size of the print, mm		Image resolution, pixels / cm	
	Width	Height	Width	Height	Width	Height
10	2048	2048	100	100	204,8	204,8
9	1536	1536	100	100	153,6	153,6
8	1024	1024	100	100	102,4	102,4
7	768	768	100	100	76,8	76,8
6	512	512	100	100	51,2	51,2
5	384	384	100	100	38,4	38,4
4	256	256	100	100	25,6	25,6
3	192	192	100	100	19,2	19,2
2	128	128	100	100	12,8	12,8
1	96	96	100	100	9,6	9,6

First stage. The respondent sat at a table with a white table-top. The lighting is the same for all respondents, the source is type F2, illumination about 550 lux. The brightness of the lighting was controlled by a luximeter and indicated on the questionnaire. The researcher spread out all the prints of the next series with a fan in a random order before the respondent, gave out a qualimetric questionnaire to the respondent, and pronounced the text of the instruction in which he suggested that the respondent order the prints from left to right in order of increasing quality. The respondent assigned points (from 0 to 100) to the quality of the prints and recorded them in the qualimetric questionnaire. Then the researcher removed the ordered stack from the respondent's field of vision and changed it to the next topic. After the respondent completed the sorting and recording of points, the researcher entered the code of each print in the appropriate fields of the qualimetric questionnaire.

The second stage of the study was devoted to the determination of the differential threshold in different ranges of permits by the method of constant stimuli. Experiments of this type are conducted to measure visual sensitivity to small changes in the stimulus. It consists in the sequence when the researcher gradually increase the resolution difference until the observer noticed the difference between the resulting resolution and the original one. Determining the differential threshold allows one to determine how much the physical characteristics of the print need to be changed so that the observer notices the difference. For the experiment, the following ranges of resolutions were taken: 8.8-25.0 pixels / cm, 25.0-50.0 pixels / cm, 50.0-100.0 pixels / cm, 100.0-200.0 pixels / cm.

The procedure for the second stage of the study is as follows. The respondent sat at a table with a white table-top. The researcher spread one image before him and suggested that he compare this one with those that he would alternately post to the respondent. The respondent was alternately presented with a print with a higher resolution, then with a smaller one. The respondent gave one of three options for assessing the quality of the impression against the first one: better, worse or equal. The researcher entered the answer in the form of a qualimetric questionnaire.

The results of the experiment were collected as a database in the MS Access. Also, when processing and visualizing the data, the applications MS Excel 2007, Origin Pro 8, Statistica 7 were used.

The sample standard deviation of the average score was determined by the formula (1):

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x_b})^2}{N_b - 1}}, \quad (1)$$

were x_i — characteristic values, — mean sample value of a characteristic, N_b — sample size.

The confidence Interval was calculated on the assumption of a normal distribution according to the formula (2):

$$\Delta x = t\frac{SD}{\sqrt{N_b}}, \quad (2)$$

were I — Student's coefficient, SD — standard deviation.

Based on the physical sense, a "sigmoid" by type (3) was chosen as a model function of "resolution - the subjective quality"

$$q(r) = 1 - \frac{r_0}{(r_0 - kr)^d}, \quad (3)$$

were $q(r)$ – the model function, describing subjectively perceived quality depending on the resolution (r), r_0, k, d – variable parameters of the "sigmoid".

The task of selecting the best parameters was solved using the MS Excel Solver module. The module changed the parameters r0, k и d so that the coefficient of determination was maximum (4):

$$R^2 = 1 - \frac{\sum(\hat{q}_i - q(r_i))^2}{\sum(\hat{q}_i - \overline{q})^2} \rightarrow max, \quad (4)$$

were $\hat{q}_i$ - mean qualimetric estimate of the stimulus with a resolution r_i observed by a respondent, $q(r_i)$ – a model estimation of the stimulus with resolution r_i, $\overline{q}$ - mean observed qualimetric estimate.

The curvature of the empirical dependence "resolution - subjective quality" was determined by the formula (5):

$$K = \frac{|(\hat{q})''|}{(1+((\hat{q})')^2)^{\frac{3}{2}}}. \quad (5)$$

The first derivatives were calculated as tangents of slope angles between adjacent observable values of the average quality estimates. The values obtained were ascribed to the midpoints of these segments. The second derivatives were calculated similarly, based on the results of calculations of the first derivatives.

The differential threshold was determined by the classical method of constructing a psychometric curve of the frequency of positive responses, which was calculated by formula (6):

$$P(+) = \frac{N(+) + \frac{N(-)}{2}}{N(+) + N(-) + N(=)}, \quad (6)$$

were $N(+)$ — number of positive responses, $N(-)$ — number of negative responses, $N(=)$ — number of “equal” responses.

In the extreme case, the psychometric curve is a "sigmoid". The differential threshold was calculated as half the interval between the "sigmoid" arguments corresponding to the frequency values of 0.25 and 0.75.

3 Results and discussion

Fig. 2 shows a family of histograms of the distribution of the frequencies of hits by ranks.

It can be seen from the figure that the probability of falling into the "own" rank (see Table 1) for the left edge of the resolution scale is quite high. As resolution increases, it gradually decreases, which leads in particular to an increase in scattering.

For all resolutions, except 153.6 pixels / cm, the highest probability is for the "own" rank assigned to this resolution (see Table 1). In Fig. 2, this is evident from the fact that the highest column is always on the diagonal. The exception is the resolution of 153.6 pixels / cm - it has a mode not in its "own" rank, its center is shifted to the tenth place. This offset indicates that the initially selected high resolutions are probably too close to each other and therefore the print with a resolution of 153.6 pixels / cm is visually indistinguishable from the print at 204.8 pixels / cm.

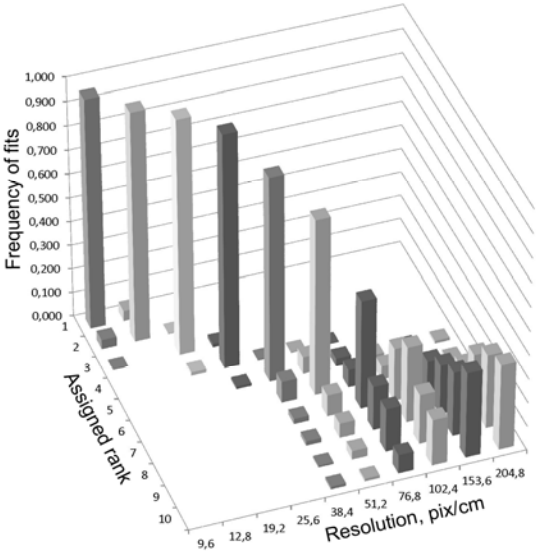

Fig. 2. Frequency distribution of hits by ranks

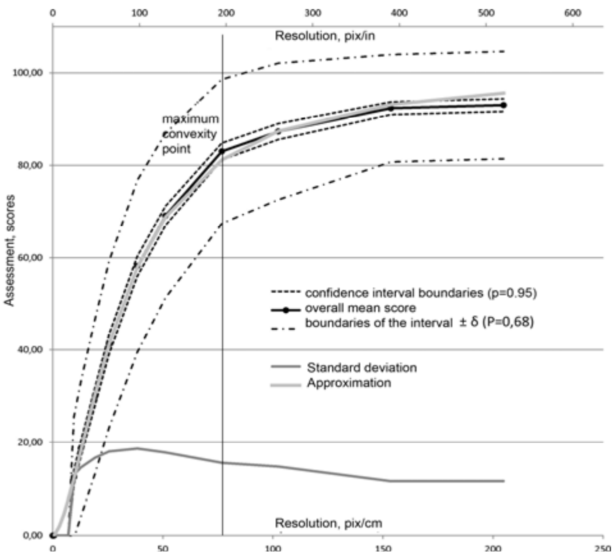

Fig. 3. Dependence of the assesstment assigned to the image on its resolution.

Preliminary analysis showed insignificance of differences in assessments for different topics. All the dependencies on the topics are in the standard deviation interval, which indicates the absence of influence of the selected topics on the perception of image quality. Therefore, assessments for all topics were combined into one sample. The dependence on the resolution of the average score assigned to the image and the confidence interval are shown in Fig. 3.

As expected, the largest spread of estimates occurs in the middle of the scale. In view of the boundedness of the scale, both the left and the right of the dispersion of the extreme estimates are smaller in comparison with the variances of estimates of the middle part of the scale. Low resolution assessments are generally in the range of 0 to 10 points, high-resolution estimates are close to a hundred. In addition, the points assigned to the intermediate permits vary depending on the individual perceptions of each respondent.

The selected (coefficient of determination 0.99), normalized to a unit interval [0; 1], the model function of the empirical dependence of subjective quality on resolution is represented by the formula (7):

$$q(r) = 1 - \frac{0.15}{(0.15+0.01r)^{1.65}} . \qquad (7)$$

The point of maximum convexity of the empirical curve 76.8 pixels / cm is found in Fig. 3 with a vertical line. It is the center of the maximum convexity interval: 64.0-89.6 pixels / cm or 162.5-227.6 dpi. At higher resolutions, the observer can determine the difference in image quality, but further increase in resolution is not justified.

Fig. 4 presents the results of determining differential thresholds for two ranges of resolutions.

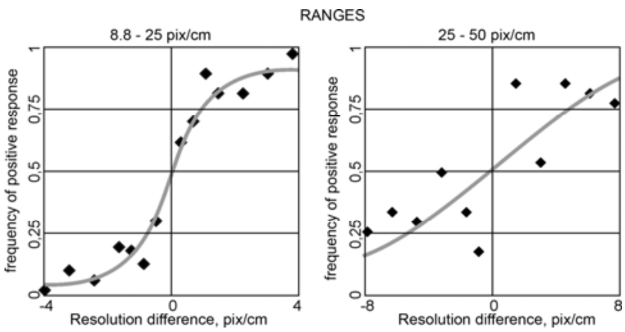

Fig. 4. Psychometric curves for differential thresholds

For the resolution interval 8.8-25.0 pixels / cm, the differential threshold was 0.8 px / cm, the relative differential threshold $\frac{0.8*2}{25+8.8} \approx 0.047$. For an interval of 25-50 pixels / cm, the differential threshold was 5.7 px / cm, the relative differential threshold $\frac{5.7*2}{50+25} \approx 0.152$. The average resolution differs by 2.22 times, and the relative differential threshold is 3.23 times. The values obtained are significantly different and suggest that the perception of achromatic images does not obey Weber's law.

4 Conclusion

In the work, the technique of qualimetric measurements of achromatic images on paper was developed and the dependence of subjectively perceived quality on the resolution of the original image was studied.

The results presented in this paper showed that the perception of quality can be well described by an asymptotically bounded function. The model function (7) is selected, which most accurately describes the dependence of subjectively perceived quality on the resolution of the impressions.

The interval of the maximum convexity of the empirical dependence of the perceived quality is determined from the resolution of the impression, above which the increase in resolution is not practically practical. It is 64.0-89.6 pixels / cm or 162.5-227.6 dpi.

For the resolution interval 8.8-25.0 pixels / cm, the differential threshold was 0.8 px / cm, and for the interval 25-50 pixels / cm - 5.7 px / cm. This means that in the 43 dpi resolution area the difference in 2 dpi is discernable, and in the resolution area of 95 dpi the difference is only 15 dpi.

In further studies on the developed technique, it is necessary to consider compressed by various algorithms achromatic images, as well as uncompressed and compressed chromatic images. To determine differential thresholds in different permission ranges, it is necessary to collect large survey statistics and to investigate the influence of gender, age and other characteristics on the subjectively perceived quality of the impressions.

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