Impact of Reproduction Size and Halftoning Method on Print Quality Perception

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Abstract: This paper presents a study related to image reproduction quality assessment. The experiment was designed to determine the impact of halftone image dimensions on the perception of image fidelity and grain structure, these two, being important quality attributes. Subjective quality assessment experiments were designed to complement recently published findings obtained by objective image metric methods for quality assessment. Image fidelity and grain structure are understandable to the observers that are not familiar with the methods used to determine image quality. These attributes are directly dependent on the chosen halftoning method. In this research, the samples were halftoned using two different types of screening methods: frequency modulation (FM) and amplitude modulation (AM) method. The experiment produced around 4000 data samples, which were analyzed by standard statistical methods. Results indicate a significant influence of the image size and halftoning method on the subjective quality assessment.

Keywords: halftoning; size of the reproduction; psychophysical experiment; print quality; image quality

1 Introduction

One of the indispensable elements of the graphic process, which always makes for an interesting topic of research, both for the scientists and industry, is halftoning. The objective of halftoning is to ensure consistent printing, along with the fidelity of reproduction. As the image consists of raster dots, it is clear that the image quality is directly dependent on the parameters that are related to the raster element. When the structure of the various IQ (image quality) metrics are analyzed, the influence of the rasterization on the image quality is somewhat disregarded. In order to use metrics for the comparison of printed image and the original, the reproduction needs to be digitalized. The goal of using metrics is to replace the human subjective factor in the evaluation of the print quality, as well as, to speed up the process of the evaluation mentioned above. The way in which metrics attempts to accomplish this is through the removal of halftones from the image. Human Visual System (HVS) is implemented by taking the image through the process of spatial filtering based on contrast sensitivity function [1]. When using the HVS, print analysis with image metrics, largely depends on the chosen method of filtering. Image metrics that use HVS is therefore not suitable for investigation of the halftone structure.

In the area of scientific research, many differences between the conventional AM screen and stochastic FM screen have been perceived and objectively measured so far [2] [3]. Color gamut, the ability of reproduction of uniform tone and color gradients [4], contrast, sharpness, the visible pattern [5]-[8] are some of the most important analyzed attributes. The first goal of this research was to show to what extent the objectively measured differences are perceived by observers. The second goal was to determine if the perception is influenced by the size of the image, keeping the viewing distance and screen ruling constant and making only the viewing angle variable.

2 Formulation of the Research Problem and Hypothesis

AM halftones have a constant dot frequency while dot amplitude is dependent upon the image gray level. FM halftone dots have fixed amplitude, but the dot distribution is variable [9] [10]. FM algorithms provide a very good representation of the original contone image, considering discretization and loss of data. The result is a high frequency isolated dot. Continuous and repeatable printing of such dot is possible only with high-quality printing systems or digital ink-jet systems with a good addressability. In the offset printing technique, imaging of printing plates is controlled directly by the computer software. Modern computer to plate (CTP) high-resolution devices are up to the challenge of imaging minute isolated dot. Research and development of different rasterization techniques were driven by the need for practical application. Apart from making the printing process possible, the goal of the halftoning is to provide the best possible quality for the given conditions. Problem emerges in the process of ink transfer from the inking unit to the printing plate, then from the printing plate to the blanket cylinder, and finally, within ink transfer process from the blanket to the substrate. The solution was a reduction of frequency using white noise middle frequencies called “green noise” [11]. Green noise is characterized by its aperiodicity, lack of low-frequency grainy structure [12], and clustering of halftoning elements. Clustering of pixel increases the halftone element, which is precisely the key to the possibility of application of the stochastic rasterization in conventional offset printing, as well as on the devices with high unreliability. This kind of approach to the solution of the problem is defined as AM/FM rasterization in research papers [13] or, more commonly, as a second generation FM. Application of the second generation FM halftone provides the possibility of defining a cluster size, i.e. its coarseness to suit various offset systems or even different printing technique like ink-jet digital printing. The final print quality in digital printing depends on: image processing, inks used, printing machine, substrate, and number of layers printed [14]. With unreliable devices, the coarseness can be increased in such a way to obtain larger halftone elements with greater constancy. The visibility of halftone can be reduced with high precision devices. By simple merging of AM halftone in mid-tones with FM halftone in highlights and shadows, a so-called hybrid halftone [2] was created. Hybrid halftone finds its application in various printing techniques, but due to its construction and specificity it will not be the object of this research. The study of image quality is multidimensional and multidisciplinary area. Print image quality can be measured objectively and subjectively. Objective print quality measuring methods are based on physical print measuring, i.e. use of measuring instruments (spectrophotometer, densitometer...), by which printing parameters, defined by external (ISO 12647, GRACol, PSO, Fogra, System Brunner...) or internal standards, are achieved. All of these standards, besides the measurement ranges, also contain photographs on test sheet for visual print evaluation. That shows the value of the subjective evaluation of the quality. Considering subjective evaluation of the quality is demanding, both in terms of time and human resources, a need emerged for development of an objective evaluation of the quality, that would replace the subjective one, but still be in high correlation with it. In order to achieve this, next to the mathematical calculation of error or noise on the image, it is also necessary to implement the influence of human visual system (HVS) [15]. The role of the HVS filter is to provide the information on whether a certain noise frequency will be visible to the human eye at a certain distance and to integrate its estimate in the evaluation of the quality of the reproduction, along with the measured values. However, contrast sensitivity function cannot be directly applied due to the complex structure of images, which is why the best algorithms for image quality evaluation do not contain HVS, but are instead based on structural or informational differences [16]. Based on the analysis so far, it can be asked if there are any other parameters that influence the perception of halftone structures with the observers. On the other hand, the size of the halftone dot, both with the AM and FM, is constructed in such a way as to not be visible to the human eye. The visibility threshold is set at four cycles per the degree of the visual angle [17]. This number of cycles correlates with the screen rulings of 110lpi. Modern offset printing processes can easily achieve screen rulings of 150 and 175lpi, which amounts to six and seven cycles, respectively, per the degree of the angle of perspective. This frequency is higher than the threshold frequency, so it can be assumed that the raster will not be visible, and therefore that the observer cannot perceive the difference in the quality of reproduction rasterized by different raster types (AM and FM) and their variations in frequency.

Based on the analysis of the available research and perceived problems in the process of reproduction of the original, two hypotheses were formulated that were tested during our research (H1 and H2) and which will be presented concisely:

H1: During the process of subjective evaluation, perception of the image quality attributes *grainy structure, sharpness and smoothness,* are influenced by halftoning method.

Differences in the properties of AM and FM halftoning can also be seen through the discretization of a contone image. The loss of information of the continuous tone image is the result of amplitude reduction to a one-bit information depth. The only way to preserve the data quantity is to increase the data frequency. With its high-frequency, FM halftone provides the preservation of a larger data quantity then AM, while at the same time preserving the information that contributes to greater image sharpness and smooth texture transitions. By changing the size of the reproduction, i.e. by increasing it, the quantity of lost information, due to halftoning, is reduced. It can be expected that with a certain increase of reproduction dimensions this advantage of FM halftone will be reduced. Dimension increase of image reproduction would consequently change the image quality perception of the observers. It can also be expected that the reproduction with higher screen ruling, of the same type of halftone, will obtain better results when evaluated by the observers, since it displays a larger quantity of information.

H2: During the process of subjective evaluation, perception of the image quality attributes *grainy structure, sharpness and smoothness* are influenced by the size of the reproduction.

Answers to research questions have to be resolved via subjective evaluation of the reproduction quality in an experiment with observers. According to the attributes defined in the epistemological study done by Pedersen and colleagues [18], grainy structure of the images, i.e. noise, sharpness and smoothness make up three of the five basic attributes of image quality, next to the color and lightness. The attributes of *sharpness*, *smoothness* and *noise* can serve as parameters for the evaluation of the quality of the reproduction done with different types of halftone, and they can be found in the evaluated parameters *the least noticeable grainy structure* and *the highest fidelity of reproduction*.

The hypotheses formulated in this paper were tested via observer's evaluations according to given parameters. The first parameter is tied to the graininess of the image [19]. The graininess of the image is defined as the noticeable low-frequency pattern of a periodic or stochastic structure. According to the literature, it is defined as a negative influence on the overall picture quality [20]. During the halftoning, i.e. discretization of the continuous tone image, undesirable patterns unavoidably occur [21], which is why their reduced noticeability is defined as an attribute of quality. Test category of the *least noticeable grainy structure* examines the quality of halftoning concerning this attribute.

The second parameter related to the evaluation of the reproduction is fidelity [22]. The goal of the examination of the high fidelity structure is to choose the image that shows the least negative attributes of halftoning.

Apart from the method of rasterization, there are other physical parameters that influence the perceived print quality, as the type of the substrate, printing technique, color, etc. [23]. In the research, reproduced images halftoned both by AM and FM screen were evaluated, with preservation of exactly the same values of parameters that can influence print quality. During the experiment, attention was directed towards a single variable, by keeping the other parameters constant. In this manner, the possible differences in visual experience of the observers, in the course of subjective evaluation, will focus exclusively on the attribute that is being varied, i.e. size of the reproduction. Test reproductions were generated in a strictly controlled laboratory environment, in order to exercise the greatest possible amount of control over all of the parameters. Psychophysical testing was conducted under standard experiment conditions while the results were processed with accepted statistical methods for independent categorical variables.

3 The Goal and Purpose of the Research

Changes in the viewing distance and the influence of the distance on the HVS were examined in order to integrate HVS in some of the accepted metrics for the evaluation of the image quality [24]. The goal of this research was to point to a single important parameter that influences the evaluation of the quality of the reproduction. The research also has a direct application in real printing systems, when considering guidelines in choosing the appropriate halftoning technique.

The purpose of the research is to develop a better understanding of the parameters that influence image quality metrics for printed images. For the purposes of this research, a unique experiment was constructed, which was carried out with the observers, both with and without their knowledge of the reproduction process. Observers type entailed the development of a test that would be understandable both to the professional and the naïve observer. The results are elaborated in a previous study by comparing the two observers group. It can be concluded that the test was appropriately constructed since there was no statistically significant difference between the answers provided by professional and naïve observers [7].

This research can contribute to the discussion about cost justification of implementing the new halftoning techniques, with more detailed view of the cost validity in relation to the production needs.

4 Description of Experimental Framework

The research was conducted utilizing a subjective quality assessment experiment. The observers had to evaluate the quality of the reproductions subjectively by using test samples with reproductions printed in four different halftones and three different sizes. In the course of choosing the halftoning method, second-generation FM halftones were considered [8]. The algorithms used were created outside the conventional CTP systems. Image halftoning of testing samples was conducted by software Raster Image Processor, compatible with PostScript 3 and PDF 1.7 files, and based on GhostScript PostScript/PDF engine. This procedure for screening was chosen because of its flexibility to obtain necessary results. For the AM raster, the Euclidian dot was used, which is the most frequently used shape in everyday printing.

The fineness of amplitude-modulated halftone is described by the number of lines per inch (lpi) while the FM halftone is defined by the size of the microdots (μm). The screen ruling and sizes of the FM raster dot that were used in the experiment were chosen based on the previous research [6]. Differences perceived by the observers will be the result of the size variable exclusively. According to the given instructions, every observer looked at thirty-six different reproductions and ranked them [25] in relation to the two parameters: *the least noticeable grainy structure* and *fidelity of the reproduction*. After the viewing process, observers were instructed to fill in the questionnaire.

The experiment was conducted with twelve different test sheets: one test was made for each of the four images distinguishable by the content in each of the three sizes. The sizes of the images were chosen in such a way as to simulate reproduction on a packaging or in a magazine. Three reproduction sizes were chosen: 62×44 mm, 88×62 mm and 125×88 mm, consequently creating three different viewing angles. Therefore, on each of the three tests sheets with different reproduction sizes there are four pictures of the same content, same size, but different halftoning method.

In order for the research to proceed, four test sheets were created, where on each of the test sheet an image of a different iconic content was reproduced. One image was presented on one test sheet but reproduced with different halftoning algorithms: two conventional (150lpi and 175lpi) and two stochastic (20 μm and 40 μm). All four test sheets with their belonging images were reproduced in three different sizes. Observers then used the ranking method and graded the observed samples, based on the test questions that they were given. The reproductions were prepared in such a way as to expect certain preferences from the observers towards a specific type of halftone. The shift in preferences on different test sheets is supposed to discover if the change in the size of the reproduction has an influence on the change in the preferred type of raster.

The transfer of the images from a digital to an analog form, had to conform to the same principles of the reduction of influential parameters to the minimum. Reduction of influential parameters entailed that all images, no matter what type of halftone was used, had to be reproduced in the same manner and under the same conditions and using the same substrates. The solution demanded the use of a printing device that would be able to reproduce the desired halftone, without modifying halftone parameters. Software RIP (Raster Image Processor) would have to override device RIP to preserve defined parameters. The reproductions were printed on a machine for print proof Epson Stylus Pro 7800, adhering to demands for the experiment. The resolution of the output device was set to 1.440 dpi, which is the maximum resolution of this printing device and enables the printing of the needed sizes of the halftone dots. Color profiles used were ISO Fogra 39 for AM and ISO Fogra 43 for stochastic one.

The printing of the samples, to be used in the test, was preceded by the calibration of the printing proof device, in order to simulate offset printing. The calibration of the output device was done with RIP software, which was to be used for the reproduction of the halftoned images. After the linearization, a halftone proofing was done. This kind of control was necessary to ensure that the printed halftone will match its digital equivalent exactly and for each dot, i.e. dot-by-dot. Comparison of the printed halftone with its digital variant was done for every type of halftone separately.

The last step in the print standardization was the calibration of the output device. Calibration was done using TECHKON SpectroDens, and, as a result, calibration curves were obtained for every color and every type of rasterization used in the experiment. The printed samples were measured by the measurement device Techon Spectroplate to confirm the screen ruling and structure of halftone dots of the printed reproductions with given parameters.

The pictures were chosen in such a way as to be mutually exclusive in the frequency of detail, smoothness, and their combination, in line with experiments of the authors that have done distinguished work in the objective analysis field of the reproduction quality [20], [26], and [27]. The four images presented on *Figure 1* were chosen.

Figure 1

Images used in the experiment: a girl (test reproduction 1), coffee (test reproduction 2), a plate (test reproduction 3), a car (test reproduction 4)

The chosen images are appropriate for the evaluation of the examined attributes of quality, a girl – close-up of a human face, coffee – large number of details, background is out of focus, a plate – many details, uniform colors, a car – presentation of a front of the car, very little detail, uniform smoothness.

The printed reproductions were placed on a neutral gray material and presented to the observers. The observers looked at the 12 panels with the reproductions, one by one and marked images, as instructed at the beginning of the experiment. In order to standardize conditions, the panels were observed in a viewing cabin under the controlled light. The strength of the light was 2200 lx, and the color temperature was 5000 K. The viewing distance was set at 40 cm. Observers analyzed four images on a single test sheet, at the same time, and subjectively evaluates the image that best reflects the given criteria: *grainy structure* and *fidelity of reproduction*. At the moment of observation, the examinee has no information about the difference between the observed reproductions, nor the type of the halftone used to produce each of the reproductions. Every test was prepared with a different allocation of images so that one type of halftone changes its position in the test. Changes in layout eliminate the possibility for the observer to exploit a pattern. The observers had unlimited time to look at the reproductions, and, respectively, for their evaluation in line with the test questions. There were a 101 observers, out of which 50 were female and 51 male, with the average age of 24.7 years. Sixty-eight of them having normal vision and 33 having their vision corrected to normal.

Since the test compares independent attributive non-parametric data, the results were processed with the Chi-square statistical analysis using SPSS Statistics v.20. These are quantitative data, i.e. frequency of choosing the observed parameter of the quality of the image for a specific independent group, respectively halftone type. This kind of statistical processing will enable determination of a significant statistical difference between the perception of the same halftone type on different sizes of the test images, as well as different halftone types on the same sample sizes. Furthermore, if the null hypothesis is accepted the dimensions of the test samples, i.e. images would have no effect on the evaluation of the parameters given. Consequently, the distribution of the observer`s answers would be the same for all three sizes, whether the distribution is coincidental or dependent upon the halftoning of the reproduction. The frequency of answers on the given parameters and their distribution according to different halftone types (20 μm FM, 40 μm FM, 150lpi AM and 175lpi AM (Fig. 2)) can also be followed.

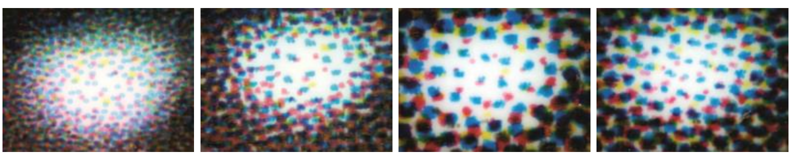

Figure 2

Magnified detail (140 ×) of the printed test reproduction 1 prepared with different halftone methods (20 μm FM, 40 μm FM, 150lpi AM and 175lpi AM)

5 Results and Discussion

In order to see which of the given images the observers evaluate as having the least noticeable grainy structure, and which ones they evaluate as having the highest fidelity of reproduction, a descriptive statistic was done for every picture separately.

A Chi-square test was calculated for each of the test sheets. A significant interaction was found for statistical significance $p<.05$. There were 24 Chi-square values in total, 12 for the least noticeable grainy structure and 12 for the highest fidelity reproduction. Table 1 and 2 shows results for test sheet 1.1 and 1.2.

Table 1
The least noticeable grainy structure
for test reproduction 1.1

	Frequency	Percent
A (20 μm)	85	84.1
B (40 μm)	3	3.0
C (150lpi)	2	2.0
D (175lpi)	9	8.9
No difference	2	2.0
Total	101	100.0

Table 2
The least noticeable grainy structure
for test reproduction 1.2

	Frequency	Percent
A (20 μm)	81	80.1
B (40 μm)	3	3.0
C (150lpi)	5	5.0
D (175lpi)	11	10.9
No difference	1	1.0
Total	101	100.0

After the analysis of each test sheet separately, a cross tabulation was done. Cross tabulation gives insight into the answer distribution for each of the reproduction sizes, so it facilitates the tracking of change in the choice depending on the change in reproduction size. The Chi-square was calculated for the reproductions of different sizes by using a contingency table.

Data analysis by a Chi-square statistical method allowed the rejection of null hypothesis and acceptance of H1 hypothesis: There is a statistically significant difference in the perception of the quality attributes of *the least noticeable grainy structure* and *the fidelity of reproduction*, dependent on the halftoning method of the image, with 95% certainty. With all of the test sheets, a statistically significant difference in the choice of preferred reproduction is shown, supporting the notion that the observers had discerned the varied parameters of the rasterization type. Finer AM screen ruling, as well as higher FM frequencies, significantly stand out in a choice of the same types of halftoning with course screen and lower frequencies. Implementation of a graphic system that could support fine screen ruling or frequency, would significantly improve the print quality. The second hypothesis analyzes the change of perception according to the two given parameters of *the least noticeable grainy structure* and *the fidelity of reproduction* depending on the image size. Each image content is analyzed separately.

Table 3
Comparative analysis of different sizes of the test reproduction 1 for the parameter
the least noticeable grainy structure

	A (20 μm)%	B (40 μm)%	C (150lpi)%	D (175lpi)%	No difference%
1.1	84.1	3	2	8.9	2
1.2	80.1	3	5	10.9	1
1.3	7.9	2	22.8	66.3	1

χ^2=165.271, df=8, p-value: 0.00

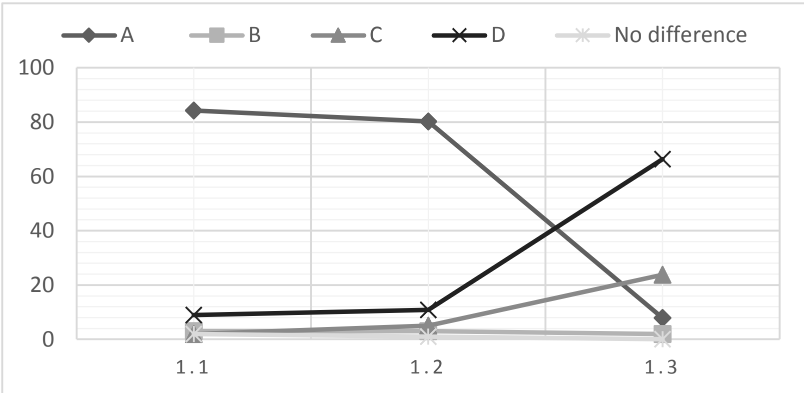

Figure 3
Observer's answers according to the parameter *the least noticeable grainy structure* for different sizes of the test reproduction 1

Table 3 shows that the observers mostly chose the FM raster (84.2%). As far as 83.5% of the observers chose 20 μm FM for the first two sizes, whereas 71.8% of observers, who chose FM raster with the smallest image size, decided upon 175lpi AM raster with the biggest image size. Therefore, the percentage of the observers who chose 175lpi AM raster with the biggest size went up to 66.3%. It can be concluded that the smaller the image is, the bigger the need is to use FM raster, by analyzing the data obtained from the test reproduction 1 (a girl). However, the situation changes drastically when the observers are shown the same image, with the same halftoning, on the same substrate, observation conditions, but with different size (Fig. 3).

Analyzing the results of 1.1 and 1.2 with a Chi-square, it was determined that there was no statistically significant difference between two images. However, the difference emerged between the middle (1.2) and the largest size (1.3). Image size 125 × 88mm has enough information to display the image with the 175lpi AM without too much data loss. As soon as the image became large enough, as to contain all the important detail, the negative attribute of FM manifested as image noise, asserted itself, while the uniform AM structure became dominant when speaking about the least noticeable grainy structure on the largest image.

Table 4
Comparative analysis of different dimensions of the test reproduction 2 for the parameter *the least noticeable grainy structure*

	A (20 μm)%	B (40 μm)%	C (150lpi)%	D (175lpi)%	No difference%
2.1	60.4	5	9.8	10.9	13.9
2.2	71.2	5	5	15.8	3
2.3	78.3	5.9	6.9	3	5.9

χ^2=21.217, df=8, *p*-value: 0.00659279

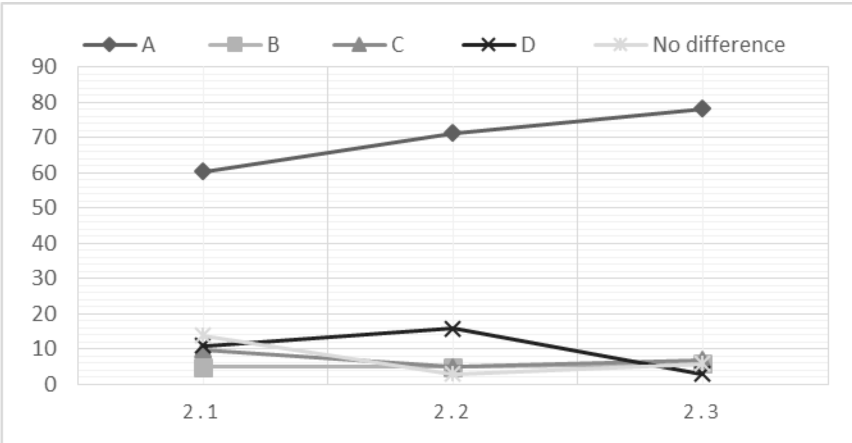

Figure 4
Observer's answers according to the parameter the *least noticeable grainy structure* for the different dimensions of the test reproduction 2

Table 4 shows the low effect of different image size on image content with high frequencies. In the case of the smallest image, most of the observers chose the 20 μm FM halftone at 60.4%, whereas this number went up to 78.3% for the largest test reproduction size. Values for the other types of halftone did not vary considerably (Fig. 4). Following this example it can be seen how the image content influences the perception of quality.

The image content is filled with details and text. Higher contrast enables the FM raster to preserve the details of the image, and hue transitions hide the noise it creates. The distribution of raster dots with the AM halftone with fixed distance between the raster elements results in the loss of detail, which is why it is perceived as the lack of information, i.e. noise. As far as the rest of the samples are concerned, an increased number of observers that was unable to choose a specific raster can be noticed, i.e. these observers did not see the difference between the different types of halftone on an image with this kind of content.

Table 5
Comparative analysis of different sizes of the test reproduction 3 for the parameter
the least noticeable grainy structure

	A (20 µm)%	B (40 µm)%	C (150lpi)%	D (175lpi)%	No difference%
3.1	63.4	6.9	13.9	9.9	5.9
3.2	63.4	4	13.9	10.8	7.9
3.3	41.5	5.9	23.8	23.8	5

χ^2=19.234, df=8, *p*-value: 0.01365708

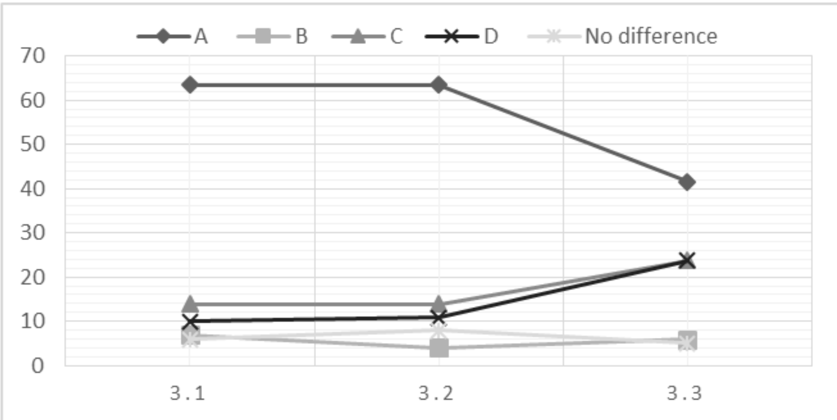

Figure 5
Observer's answers according to the parameter
the least noticeable grainy structure for different sizes of the test reproduction 3

In Table 5 percentages for the choice of FM decreased from 63.4% to 41.6% for the first two sizes with the largest reproduction, indicating increased perception of grainy structure on this size. Periodical type of halftone went up from 13.9% and, respectively, 10.9% to 23.8% on the largest reproduction. Test reproduction 3 has a combination of elements with plenty of detail and elements with smooth tonal gradations.

It can be seen, by analyzing the results, that with the increase of the image size a statistically significant difference, in the perception of the image, emerges. With smaller image sizes, FM halftone is dominant since it allows for a much better detail preservation (Fig. 5). Since the observed surface is smaller the noise on the image is not so obvious. With the largest test sample, a confrontation becomes inevitable between the elements with minute details and the surface with smooth tone transitions that start to show the signs of noise. This can be observed in the reduction of FM halftone percentage from 63.4% to 41.6%, and rising of percentage for AM from 13.9% at 150lpi and 10.9% at 175lpi to 23.8% for each of the AM halftone, which is why one can say that AM raster takes over in dominance for the attribute of least noticeable grainy structure, at this image size.

Table 6
Comparative analysis of different sizes of the test reproduction 4
for the parameter *the least noticeable grainy structure*

	A (20 μm)%	B (40 μm)%	C (150lpi)%	D (175lpi)%	No difference%
4.1	85.1	5.9	3	4	2
4.2	84	3	5	5	3
4.3	88.1	5.9	2	1	3

χ^2=5.55, df=8, *p*-value: 0.69749434

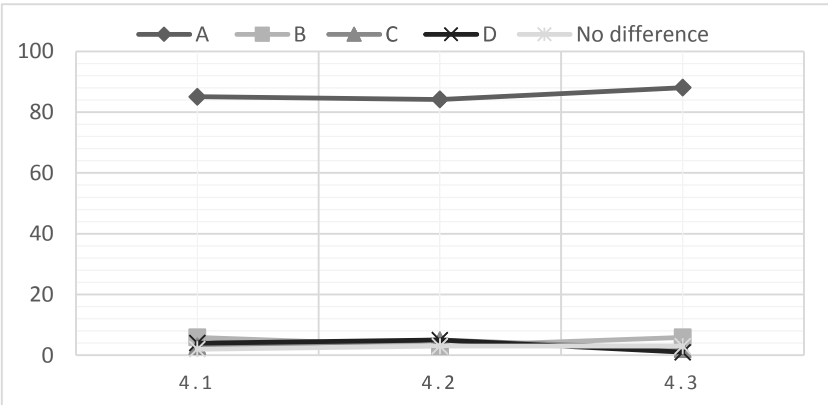

Figure 6
Observer's answers according to the parameter *the least noticeable grainy structure* for the different sizes of the test reproduction 4

Tables 6 and Figure 6 show that the car picture has no statistically significant differences in quality evaluation dependent on the size of the sample. Here the observers primarily choose FM 20 μm halftone. The cause can once again be found in the characteristics of both types of the screens.

Table 7
Comparative analysis of different sizes of the test reproduction 1 according
to the parameter *the fidelity of reproduction*

	A (20 μm)%	B (40 μm)%	C (150lpi)%	D (175lpi)%	No difference%
1.1	50.5	3	9.9	35.6	1
1.2	39.5	3	19.8	34.7	3
1.3	6.9	7.9	34.7	49.5	1

χ^2=59.996, df=8, *p*-value: 0.00

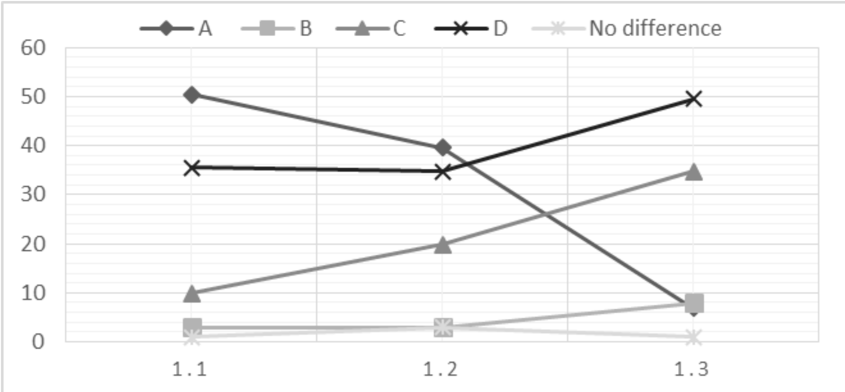

Figure 7
Observer's answers according to the parameter
the fidelity of reproduction for the different sizes of the test reproduction 1

On the smallest reproduction the expected distribution of the answers in favor of the 20 μm FM halftone can be seen, while already at the next size that percentage is reduced in the favor of 175lpi, which is, with the biggest reproduction, together with 150lpi AM, jointly they feature the highest fidelity of reproduction with over 80% (Table 7). Perceived quality of FM has dropped dramatically (Fig. 7), due to increasing in perceived graininess on images. Larger viewing angle, for this type of image content, enables uniform AM structures to be seen as reproduction with more fidelity than FM halftone.

The images that represent humans and faces are especially sensitive to the loss of detail. As one of the most common forms, each and every irregularity on a face or a human being is easily noticeable, hence the observers responded in such a way to the content of this image. The situation with the fidelity of the image is similar to the situation with the graininess. With the smallest size, the 20 μm FM raster is dominant while already at the medium size there is no statistically significant difference between the AM and FM. With the largest reproduction, the observers choose the AM halftone for the attribute *fidelity,* whereas the FM raster losses its fidelity because of the noise.

Table 8
Comparative analysis of different sizes of the test reproduction 2 according to
the parameter *the fidelity of reproduction*

	A (20 μm)%	B (40 μm)%	C (150lpi)%	D (175lpi)%	No difference%
2.1	52.6	7.9	6.9	16.8	15.8
2.2	53.5	4	10.9	25.7	5.9
2.3	65.3	4	13.9	9.9	6.9

χ^2=19.686, df=8, *p*-value: 0.011

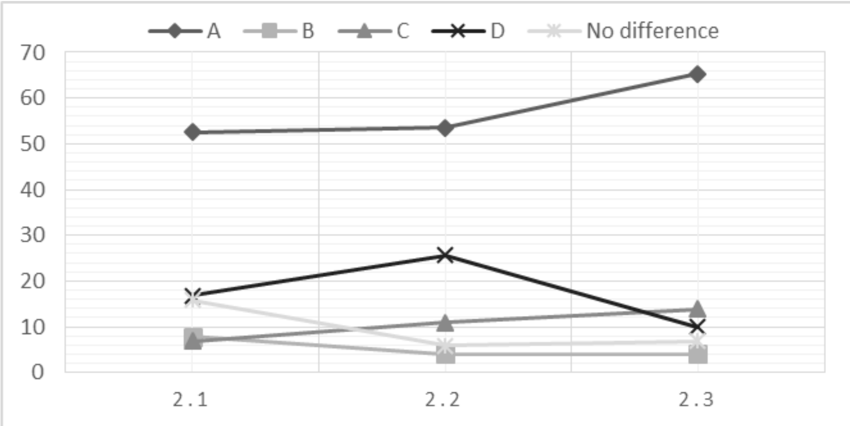

Figure 8
Observer's answers according to the parameter
the fidelity of reproduction for the different sizes of the test reproduction 2

On Figure 8, the distribution of the observer's answers for the reproduction 2 can be seen. Increasing the size of the image makes the FM halftone perceived as a high-fidelity image, with the choice frequency of 65.3%. It can also be seen (Table 8) that it held the greatest percentage without regard to the size of the test image, and with the increase of the size, the choice frequency also went up.

By analyzing the cross-tabulation data it can be noticed that the observers that choose the 175lpi AM halftoned image as the best for the middle size image, gave the advantage to the 20 µm FM halftone in the case of the largest image size. As far as 75.9% of those that gave the advantage to FM raster in the case of the middle size stayed true to their choice and chose it again in the case of the largest size. For other halftone types, it can be concluded that there is much indecisiveness on the part of the observers and that their answers differ according to the different sizes of the sample.

Table 9
Comparative analysis of different sizes of the test reproduction 3
according to the parameter *the fidelity of reproduction*

	A (20 µm)%	B (40 µm)%	C (150lpi)%	D (175lpi)%	No difference%
3.1	47.5	5.9	16.9	18.8	10.9
3.2	47.5	7.9	14.9	15.8	13.9
3.3	29.7	6.9	19.8	32.7	10.9

χ^2=13.924, df=8, *p*-value: 0.083

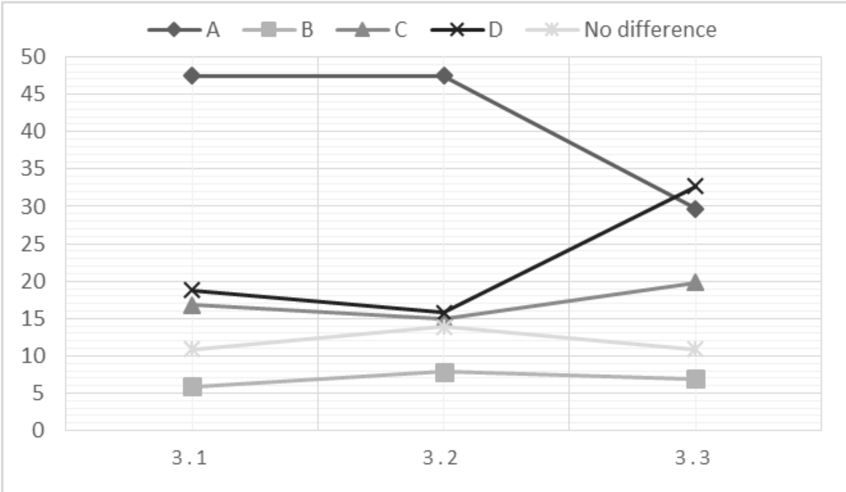

Figure 9
Observer's answers according to the parameter
the fidelity of reproduction for the different sizes of the test reproduction 3

Table 10
Comparative analysis of different sizes of the test reproduction 4
according to the parameter *the fidelity of reproduction*

	A (20μm)%	B (40μm)%	C (150lpi)%	D (175lpi)%	No difference%
4.1	69.3	4	12.2	9.9	4
4.2	62.4	5	11.9	12.9	7.8
4.3	60.4	7.8	14.9	12.9	4

χ^2=5.07, df=8, *p*-value: 0.750

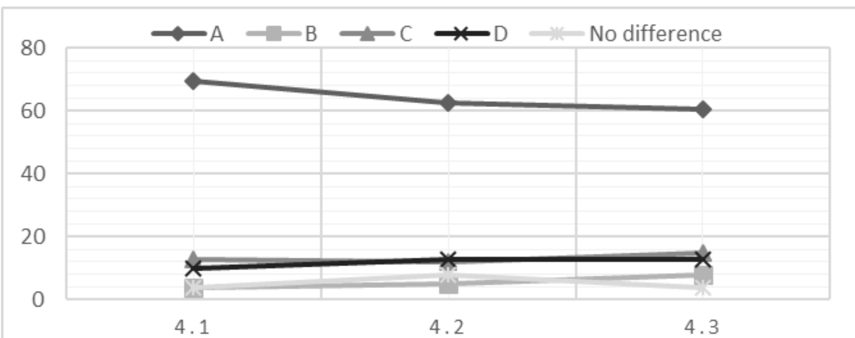

Figure 10
Observer's answers according to the parameter
the fidelity of reproduction for the different sizes of the test reproduction 4

Table 9 shows that test reproduction 3 has a statistically significant difference when examining high-fidelity attribute. On the smallest sizes, the FM halftone was marked as high-fidelity with 47.5%, while with the largest size the AM halftone was marked as the best with 32.7%, but the 20 μm FM was very close to AM with percentage of 29.7% (Fig. 9). By analyzing the cross-tabulation it can be seen that the largest number of the observers who marked the FM halftone as the best for the smallest and medium sizes of the test reproductions, chose the AM halftone as the best for the largest reproduction, which leads to the conclusion that there is a statistically significant difference in the choice of a specific halftone for the attribute of fidelity.

Figure 10 shows the very stable percentage of the observer`s choices, 20 μm FM halftone, without regard to the increase in the size of the reproduction. With the fourth image, there were no oscillations in the perception in the course of changing the size of the reproductions (Table 10). The picture consists of large surfaces with smooth tonal transition, which makes the observers choice interesting, since they choose FM with both parameters and all sizes as the high-fidelity reproduction. Halftone dots distributed in patterns are more pleasing to the eye of the observer when looking at uniform tone, which makes this result unexpected. The reason for this result can be also found in the definition of the parameters that the observers had to mark. Fidelity of the reproduction is a very broad term, which is synonymous with the universal image quality.

The research has shown that there is a statistically significant difference in the attributes of quality, *the least noticeable grainy structure*, and *the fidelity of reproduction*, in relation to the size of the image, which allows the H2 to be accepted.

Conclusion and Future Work

Considering the size of the halftone dot, viewing distance and conditions constant, and by varying only the size of the images, the conclusion can be reached that the perception of the halftone quality varies. Concerning *the least noticeable grainy structure*, an overall discussion of the results can be done. Combining the Tables 3-6 higher quality can be seen on smaller images, produced with 20 μm FM halftones. Tables 7-10 show that, regarding *fidelity*, FM halftone is less dominant but is still the best choice, when it comes to images with the smaller size. Increasing the size of the image will cause changes in the perception of reproduction quality, depending on the halftone and image content. On some content types, larger images show higher quality when they are rasterized by AM halftone. By analyzing the image content and the observer’s answers, it can be seen that the biggest variation appears with the content that combines the elements of fine tone gradients and small details. The difference in the amount of information between the contone image and halftone image is reduced by increasing the size of the reproduction, which directly reflects on the increase of detail display with AM raster. The increase in the detail displayed by the AM raster, correlates positively, with the perceived picture quality. With the highly detailed images having sharp contrast and dynamic range, the change in the size of the image influences the quality of the FM raster in a positive way, making it a recommended option in the case of images with such content. Based on the data analysis and other images of different content, it can be concluded that the change in the perceived quality of AM and FM halftone would happen, but only in the case of a more drastic size increase. Smaller images are more suitable for FM halftone reproduction. The threshold at which the AM rasterized image will be perceived as having better quality is dependent on the image content. Images with the combination of fine tone gradients and contrastive fine details have been shown to be the most sensitive to the size change. Further research is needed in order to establish a more precise connection between the amount of detail in the image, image size variation and the amount of data preserved in the image after the halftoning process. Including this data in the metric algorithms could provide new objective methods for determining the quality of printed reproduction. Comparison between AM and FM halftone is often done with subjective methods. Subjective research has a tendency to produce conflicting results, which is the reason the researchers often concluded that further research is needed to determine the reason for such oscillations. Conclusions of this research, stemming from the experiment, directly contribute to a better design of subjective assessments of print quality. It aids the researchers in obtaining the most consistent results possible and more clarified conclusions about different raster techniques.

Additional conclusions can be reached about the implementation of new raster techniques into the production system. Implementation of the new halftoning techniques carries different challenges, both technical and financial. The results of this paper can be of help in the process of weighing the possible benefits or negative results. By simple analysis of the graphic products that will be realized by the system, one can reach a more informed and profitable decision on which type of halftone to use. This decision can then be used in the course of implementation of a new halftoning technique in the desired graphic production system.

Use of both type of halftones on the press sheet provides the ability to exploit the positive characteristics of AM and FM. In order to fully exploit the potentials of raster techniques, the development of XM (Cross Modulated) algorithms should incorporate image content analysis. These are the attributes that can lead to an improvement of the distribution of AM and FM areas during the RIP process. This kind of approach would enable the choice threshold to contain more than just the gray level of halftone, but also additional parameters that would contribute to a better distribution of AM and FM halftones.

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