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The Influence of Image Capturing Systems on Artwork Reproduction

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Can we assess artwork reproduction from the standpoint of properly adjusted image management process? This study integrates the analysis of artwork reproductions obtained by three different image capturing systems. The artwork examined in this study belongs to the bright-shadow, visually presentable category and the reproduction quality analysis was performed visually and instrumentally. The visual study included formal/methodological characteristics of the artwork. The purpose of this research is to determine whether there is any correlation between subjective and objective reproduction assessment when using different image capturing systems. Based on the results acquired, it has been shown that brightness is decisive for quality reproduction. This finding has been confirmed by instrumental measurement and visual evaluation. However, artwork that belongs to different visually presentable systems may require other criteria for the evaluation of quality artwork reproduction.

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Introduction

Material and visual structure represent the defining characteristics of a painting if it were made by the technique of oil on canvas. Formal/methodological characteristics complement the description with the dimensions of visual presentation. Visually presentable systems represent the combinations of the optical structural elements in groups of recognizable wholes that can be interpreted by the human eye, more or less objectively. Structural elements are point, line, plane, volume and color. In two-dimensional media the volume is represented by continuous tonality. Based on the structural elements visually presentable systems can be defined as linear, one-dimensional, tonal and colorist. In literature one can find the bright-shadow system[1] (*Clair-obscure*, French; *Chiaroscuro*, Italian; *Helldunkel*, German) as a separate visually presentable system. It represents primarily the combination of one-dimensional and tonal systems. The tonality represents the transition between the planes of different brightness in a very narrow area. The totality of the form is thus divided by tonal system into planes which are defined by their brightness.[2] Conceptual significance of bright and shadow is the dynamic of presentation, aiming exclusively towards the rhythm of the image. The dynamic expression of art is often used to represent psychological states, independent of media. The information concerning color may be reduced in order to strengthen the dynamics of form. Therefore, there is a tendency towards the monochromatic where tone is the dominant medium of expression. This visually presentable system appeared in the period of the late Renaissance, and it achieved its culmination during the Baroque period. It is often used today for expressing dynamics in art works.[3,4]

Studies have shown that it is necessary to implement formal and methodological criteria during the process of storing digital databases of artwork. Such databases may be used for archives[5,6] or reproduction in monographs and other media. The formal criteria concern structural elements of visual form, while methodological criteria apply to characteristics and materials of implementation.

The reproduction process begins with the photographing of paintings. In the technological proess of painting reproduction, two ways of getting information are used: conventional (film-based) and digital.[7] The conventional method is characterized by the usage of photographic film as the optical media for storage of information about the painting. Depending on the material and the reproduction process, photographic film can register naturally visible colors through continuous tonal shades from the lightest to the darkest ones, from non-saturated to partly saturated pure colors.[8]

The digital method is based on the direct input of information about the painting as an array of pixels. To obtain information digitally, digital cameras and scanners are used now-a-days. The working principle of the digital camera is similar to that of the conventional: the incoming rays are focused by the lens onto a photosensitive surface, on which the image is formed.[9] The difference between conventional and digital cameras is in the photosensitive surface. Conventional cameras use photographic film while digital cameras have image sensors.

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Color Plate 8 is printed in the color plates section of this issue, p. 239.

A scanner transforms the information about the painting into the digital form from analog signals. The information about the painting is transferred in accordance with the scanning pattern defined by resolution and the number of grey levels.[10] The disadvantage of the scanner system is the limited size of the scanner surface. One obvious quality feature is the image definition, which can be established at a deliberately low level in the original for artistic reasons, or may be limited by the resolution when scanning the original and transferring it to film, plate, or substrate. The image information is not transferred entirely, but only in accordance with the scanning pattern of a specified resolution and finite number of tonal value, or gray, levels. The pattern consists of the smallest image elements resolved by the scanning device, the pixels. This is the scanning frequency (spatial frequency), also known as scanning resolution.

The pixel pattern must be significantly finer than the image detail. There is another important aspect for the selection of scanning frequency: the image data should use the minimum of memory space. Doubling the scanning frequency quadruples the size of the file. A good compromise is reached between the reproduction of fine details and the size of the file, if the factor F in the following equation is given a value of two:

$$\text{Scanning frequency} = F \times \text{magnifying factor} \times \text{screening frequency}$$

Under normal circumstances, each screen cell on the output side is assigned four input pixels, one pixel covering a quarter of the area (due to $F = 2$). The mean is found from the tone values (gray levels) recorded from scanning the four input pixels and the result is stored in memory. The mean produced in this way balances the slight, equipment-related variations of the light sensor in the input scanner, and brings about a more even representation of smooth tint areas.

In the case of halftone imagery, "screen frequency" is sometimes referred to as screen ruling. The metric unit of scanning or screen frequencies is usually l/cm or cm^{-1}. Often used is the US-based "dpi" as an abbreviation of "dots per inch." If the demands imposed on the image definition are not very exact, and the memory requirements are low, lower resolution is used for scanning. If an image is to be output as a halftone on film, plate, or directly on a print substrate, the dot shape, screen frequency, and screen angles must be specified first. Since the dots to be written are made up of individual pixels, the pixel size must be specified correspondingly.[7]

Experimental

The idea of this work is to determine aberrations in the reproductions of paintings as a consequence of capturing images with different systems. The investigated painting oil on canvas artwork. It belongs to the visually presentable system of bright and shadow by its formal and methodological characteristics and is shown in **Color Plate 8(a) p. 239**. This visually presentable system incorporates the light and dark parts of the painting divided into separated forms independent of their conceptual meaning. It is characterized by expressiveness of details and form characteristics. The aberrations that appeared are observed in the context of the formal and methodological characteristics of the painting.

TABLE I. Systematization of reproductions in accordance with the image capturing systems

Reproductions	Image Capturing Systems
1	scanner
2	conventional camera
3	digital camera

The Reproduction Process Parameters

The painting and a Gevaert-Macbeth control strip (**Color Plate 8(b) p. 239**) were photographed simultaneously by the following image capturing systems: scanner, conventional camera and digital camera.

Image capture with conventional and digital cameras was performed simultaneously during daylight, i.e., noon sunlight on a clear day with color temperature.

The conventional camera Nikon F90X was used with Fuji Provia™ 100ISO 35 mm slide film processed by E-6. The developed film was scanned on a Topaz II Heidelberg flatbed scanner with resolution of 300 dpi with respect to the size of the original painting. The captured image covered approximately 80% of the total film area. The digital data represents image capture by a conventional camera.

The digital camera Canon Power Shot™ A20 was used with resolution of 1200×1600 pixels (nominal 2 megapixel sensor). The captured image covered approximately 85% of the total digital image area. The digital data thus obtained represents image capture by digital camera.

Direct scanning of the painting was done on the Tpoaz II Heidelberg flatbed scanner as a resolution of 300 dpi 1:1 scale. The digital data obtained represents the direct scanning system.

The acquired digital data was resampled with the same image size at 4.8 MB and processed in Adobe Photoshop 6.0. All digital data were corrected the same way, using curves for getting adequate image contrast and the hue/saturation dialog box option for improving chroma. From the digital data, the films of the separated colors were made for offset printing by using a frequency-modulated screen (FM screen) with a dot size of 20 μm. The reproductions were printed on a four-color offset Heidleberg Speedmaster 102 machine. The white nature paper Euro Art Matt was used for printing, 115g/m^2, produced by M-Real Corporation, Germany.

Three offset reproductions (15×11.7 cm) were obtained and correspond to the three image capturing systems as shown in Table I.

The Choice of Methods for Evaluation of Painting Reproductions

The evaluation of the reproduction in relation to the painting was performed by

- visual evaluation and
- instrumental spectrophotometer measurement.

For visual evaluation, experts from the field of the visual arts were consulted. The majority of observers however, were undergraduate students from The Faculty of Graphic Arts and had normal color vision according to the Ishihara test. They had experience in scaling color differences. The choice was made in order to obtain the evaluation from a purely aesthetic point of view. These observers were persons in the age range of 25–30 years, in total 150 observers (80 female and 70 male) were involved.

The visual evaluation was performed according to the conditions set by ISO 3664 standard.[11] Visual evaluation was carried out in an experimental booth. The inside of the experimental booth was illuminated by broadband F7, CCT 6500K Ra 90 fluorescent lamp. Luminance level was 360 cd/m^2. The painting and the reproduction were placed on the floor of the booth side by side. The floor of the booth was matte of middle lightness. The booth's interior walls were matte and neutral. The illumination was centered perpendicular to the plane of the painting and reproduction. The observer was about 30 cm from the opening of the booth. The observation angle is 45° from the normal to the painting and reproduction. The same distance from the specimens was maintained during visual evaluation. The overhead light was turned off. Prior to the visual assessment, the observers were asked to adapt to the test illumination for 60 seconds.

The aberration judgments are given on the basis of the following criteria:

1. **Excellent** (there is no color difference between painting and reproduction; the range of brightness within the light and dark parts of the reproduction is well reproduced; the tone gradient between darkest and lightest areas of reproduction is clearly observable; good contrast is achieved by the difference between darkness and lightness)
2. **Very good** (there is very small color difference between painting and reproduction; the range of brightness within the light and dark parts of the reproduction is well reproduced; the tone gradient between darkest and lightest areas of reproduction is clearly observable; good contrast is achieved by the difference between darkness and lightness)
3. **Acceptable** (there is very small color difference between painting and reproduction; the range of brightness is lower within the light and dark part of the reproduction; the tone gradient between darkest and lightest areas of reproduction is clearly observable; lesser contrast achieved by difference between darkness and lightness in the reproduction)
4. **Still acceptable** (there is greater color difference between painting and reproduction; the range of brightness is lower within the light and dark parts of the reproduction; the tone gradient between darkest and lightest areas of reproduction is less clear; lesser contrast is achieved by difference between darkness and lightness in the reproduction)
5. **Unacceptable** (there is great color difference between painting and reproduction; the range of brightness is the low within the light and dark parts of the reproduction; the tone gradient between darkest and lightest areas of reproduction is not well observable; even less contrast is achieved by difference between dark and light areas of the reproduction)

Gevaert-Macbeth control strip and its reproductions made alongside with the painting reproductions were used for instrumental measurement only The Gevaert-Macbeth control strip contains solid patches of primary and secondary colors and the grey wedge. Instrumental measurements were performed on an X-RiteColor Digital Swatchbook spectrophotometer. On solid patches of primary and secondary colors the reflection factor was measured and it is presented in CIELAB color space.[12,13] On every patch of the grey wedge, the reflection factor was measured, and color densities of cyan, magenta, yellow and black present these values. The measuring geometry was 45/0. Each patch was measured on three spots, and the result was their average value.

TABLE II. Results of the Visual Evaluation of Reproduction Observers in Relation to the Painting

Reproductions	Image Capture Systems	Subjective Evaluation
1	scanner	acceptable (89%)
2	conventional camera	very good (84%)
3	digital camera	unacceptable (61%)

Results and Discussion

In reproduction of paintings different equipment, processes, systems and materials are used. Each of the mentioned parameters has a determined influence on the reproduction of the painting. Image capturing systems is the first variable in the reproduction process, which can lead to a better or poorer reproduction.[14–16] On the basis of the experimental investigations, using subjective and objective methods, this work primarily has to determine how much the image capturing system may influence the reproductions. As previously mentioned, this painting belongs to a visually presentable bright-shadow system. The aim of this study is to determine whether the evaluation done by observers correlates with results obtained by instrumental measurements.

In the experimental part the printing conditions were defined and constant for all the reproductions so that the changes that happened were caused exclusively by the different image capturing systems. The investigation results are presented by the judgments of visual evaluations of the observers and spectrophotometer analysis of color aberration and reproduction contrast in relation to the painting.

Subjective evaluation, which presents the first experience of the reproduction, was one of the methods of reproduction quality judgment. Based on the assessment of 150 observers, who separately evaluated the reproductions under controlled conditions, the results (Table II) showed that the most acceptable way of image capturing was by conventional camera. Evaluations of the visual judgment of observers of single reproductions are given in the table.

The objective method (instrumental spectrophotometer measurement) was then used for color analyses obtained by different image capturing systems. The histograms shown in Figs. 1 and 2 demonstrate the modification of lightness (ΔL^*), chrome (ΔC^*), and hue (ΔH^*) of the reproductions relative to the original, as well as total color difference. Based on the mathematical expression for determining the total color difference ΔE^*_{94}.[17]

$$\Delta E^*_{94} = \sqrt{\left(\frac{\Delta L^*}{k_1 S_1}\right)^2 + \left(\frac{\Delta C^*}{k_c S_c}\right)^2 + \left(\frac{\Delta H^*}{k_h S_h}\right)^2} \tag{1}$$

where:

Chroma (C_{ab}^*) = $(a^{*2} + b^{*2})^{1/2}$; hue angle (h_{ab}^*) = $\arctan(b^*/a^*)$; $S_l = 1$; $S_c = (1 + 0.045\ C^*_{ab})$; $S_h = (1 + 0.015\ C^*_{ab})$; and k_l, k_c, k_h are parametric factors which have a default value of unity.

The aberrations of single colors are calculated according to the defined acceptability criteria:[18]

$\Delta E^*_{94} \leq 3.0$ acceptable (visually acceptable sample deviation toward the standard)

$\Delta E^*_{94} > 3.0$ unacceptable (visually unacceptable sample deviation toward the standard)

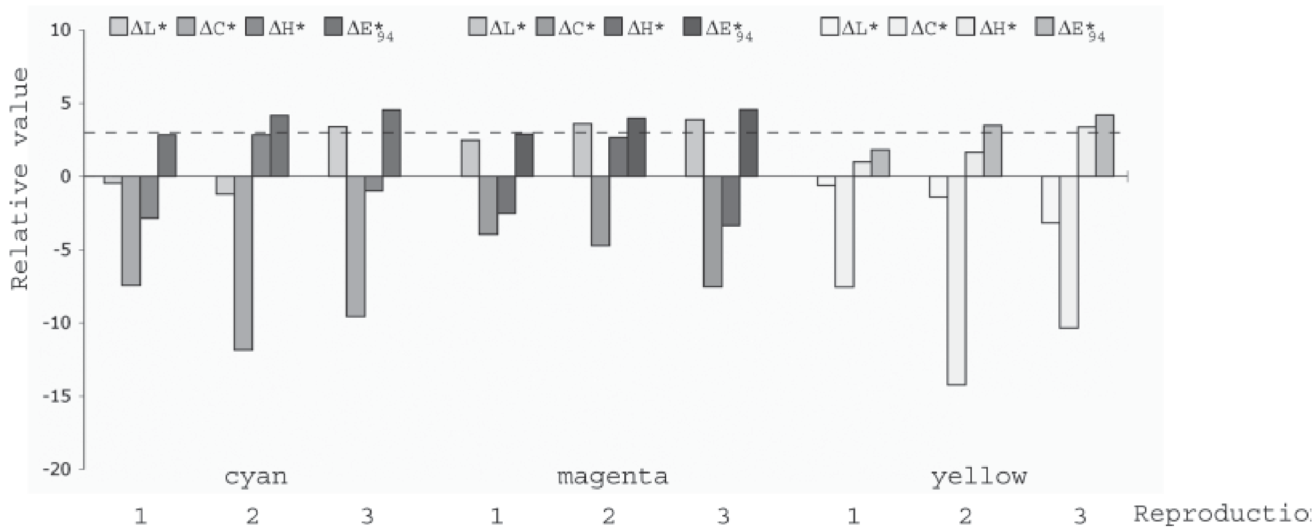


Figure 1. Histogram presents the changes of ΔL*, ΔC* and ΔH* and total color differences ΔE^*_{94} of the reproductions of primary colors in relation to the control strip (standard)

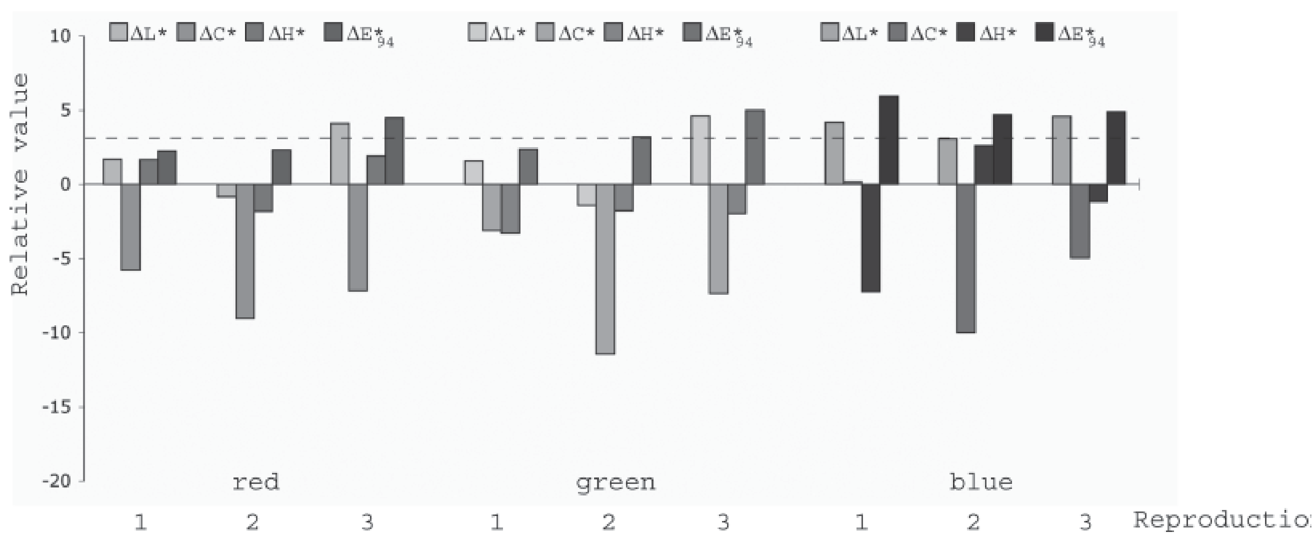


Figure 2. Histogram presents the changes of ΔL*, ΔC* and ΔH* and total color differences ΔE^*_{94} of the reproductions of secondary colors in relation to the control strip (standard).

On the basis of the obtained values of the total color differences ΔE^*_{94}, and the separate relationships of the image capturing system to the single colors presented in Figs. 1 and 2, it is apparent that the smallest aberrations are obtained with the scanner system and the greatest ones with the digital camera. The differences within a particular color for each image capturing system are also smaller. The total color difference, calculated on the basis of the expression ΔE^*_{94} does not correspond to greater or smaller aberration. In order to get the complete answer to the question, which one of the color characteristics (lightness, chroma or hue) influences the acceptability of reproduction in particular image capturing system, further analysis has been performed. With this analysis the changes of lightness, chroma and hue of reproduction in relation to the painting have been observed.

The reduction of chromaticity in primary colors is greatest with cyan and yellow, and smaller with magenta (Fig. 1). The secondary colors (red, green, blue) illustrate uniform reduction of chromaticity, where it is more influenced by the image capturing system (Fig. 2). The chromaticity is mostly reduced with the conventional camera and least with the scanner. Since the chromaticity change is greatest for yellow and total color difference is within tolerances, one can say that chroma change does not greatly influence achieved total color differences.

The change of lightness is smallest with yellow, where it is reduced with all image capture systems. Using the scanner and the conventional camera, the lightness of cyan was reduced, but it was increased by the digital camera (Fig. 1). The change of lightness is smaller with red and green using the conventional camera, while it is increased with the digital camera and the scanner (Fig. 2). The lightness of magenta and blue is increased with all image capture systems (Figs. 1. and 2). The change of lightness represented a significant influence

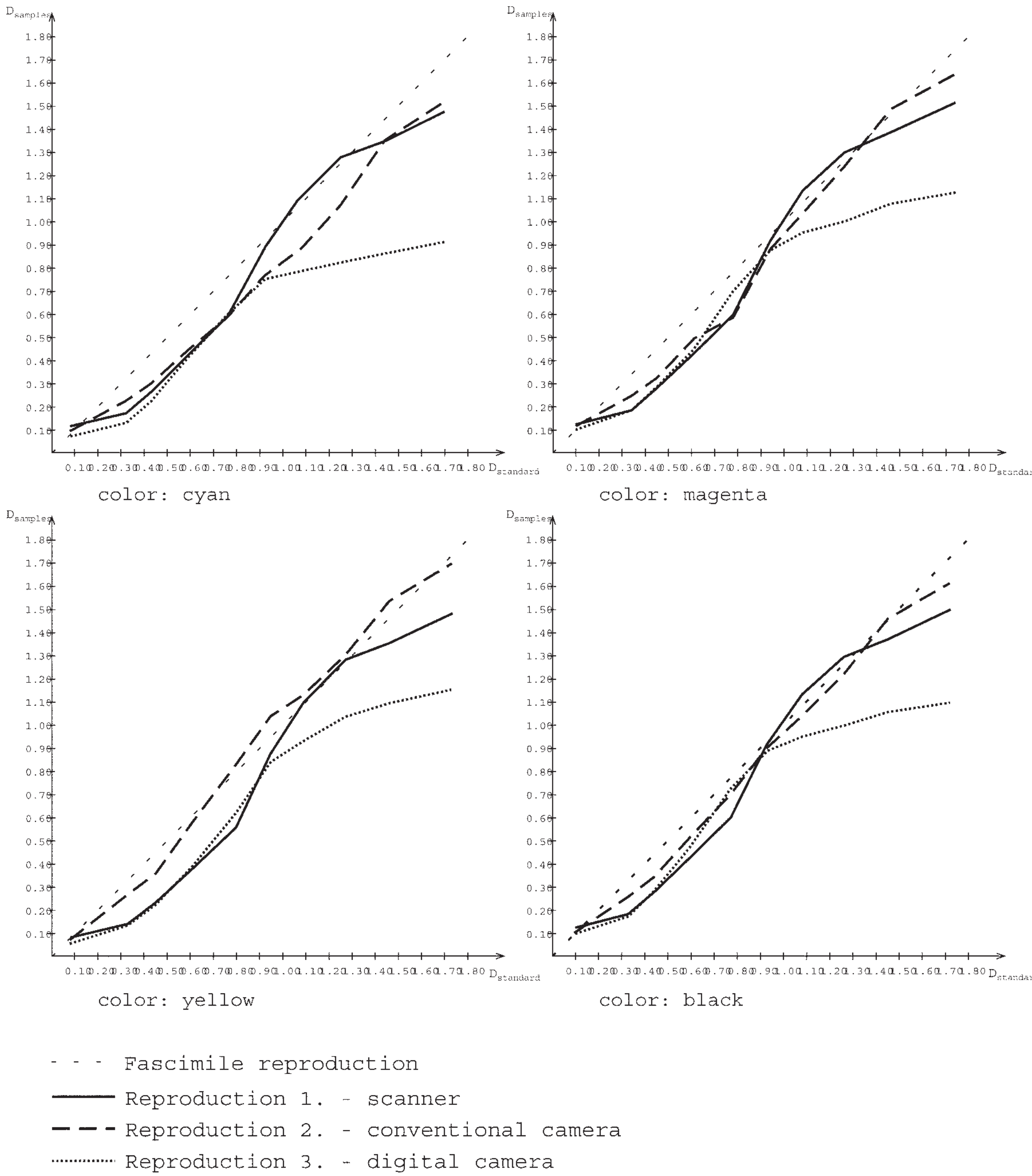


Figure 3. Color reproduction curves of samples produced by different image capturing systems.

on total color difference. The hue variation with yellow is towards the green area of the color gamut, while with green it is towards the yellow area using all image capturing systems. Cyan exhibits a shift of hue towards green using the digital camera, while the change is towards blue when using the conventional camera.

The hue variation when using digital camera and scanner with blue is in the direction towards cyan, while it is towards magenta with the conventional camera. With red and magenta there is a tendency to merge when using the conventional camera. When using the digital camera and the scanner there are shifts of hue from red to yellow and from magenta to blue. The hue does not demonstrate great influence upon the value of total color difference achieved.

The analyses have shown that the greatest influence on the total color difference is accomplished by change of lightness with smaller influences from changes in hue and chroma. The greatest change of chromaticity is yielded by the conventional camera, and the greatest change of lightness by the digital camera.

A further analysis relates to the change of contrast in reproductions. The reflection measurement was made on every patch of the grey wedge (10%–100% value of hue) of control strip. The values are presented in color densities and they are shown with color reproduction curves (Fig. 3).

Based on the color reproduction curves (Fig. 3), which represent the correlation of the painting and the reproductions, each color has been investigated separately:

TABLE III. Values of the Direction Coefficients *k* and the Coefficient R^2 for Linear Regression Equations of the Reproductions.

Reproductions	Color							
	Cyan		magenta		yellow		black	
	k	R^2	k	R^2	k	R^2	k	R^2
1	0.9806	0.9638	0.9943	0.9603	1.0009	0.9572	0.9930	0.9639
2	0.9278	0.9896	1.0117	0.9900	1.0532	0.9906	0.9969	0.9933
3	0.5911	0.9045	0.7190	0.9238	0.7810	0.9456	0.7102	0.9113

cyan, magenta, yellow and black. By linear regression[19] the aberrations of the color reproduction curves from facsimile reproduction (angle 45°) have been calculated. The aberrations are presented by slopes of the regression lines, k, and by coefficients of R^2. The slopes are calculated on the basis of the expression: $y = kx + b$, where the coefficient of the direction of the straight line is $k = tga$, and b is the intercept on the axis y. The determination coefficient R^2 has values between 0 and 1, 0 = R^2 = 1. It is calculated in the visual image. Values of k and R^2 for each color are given in Table III.

The smallest aberrations from the facsimile reproduction (angle of 45°) are obtained by the image capture using a conventional camera and scanner, which is obvious from the slope k (Table III). The coefficients of variations R^2 (Table III) show almost linear reproduction, independent of the image capturing systems. The greatest aberration within the image capturing systems is visible in the reproduction of yellow. It is obvious that the conventional camera yields the best contrast when comparing color reproduction curves. This was proven with subjective evaluation as well. Reproductions captured by the digital camera and the scanner show the greatest aberrations of all the colors at higher values of color densities. Using the digital camera there is almost no difference in the values of the color densities greater than 1.10 (which corresponds to the screen value of 70%). This means that the values of color densities of the painting greater than 1.10 are reproduced with the same values of the color densities in the reproduction with this image capturing system. In practical example it means the decreasing of contrast and loss of dark tones in the reproduction, as is apparent from the values of the slopes, k (Table III).

Conclusion

The visual evaluations of observers (Table II) have shown that the conventional camera is most acceptable image capturing system for reproduction of a picture that belongs to the bright-shadow visually presentable system. This has been confirmed by instrumental methods.

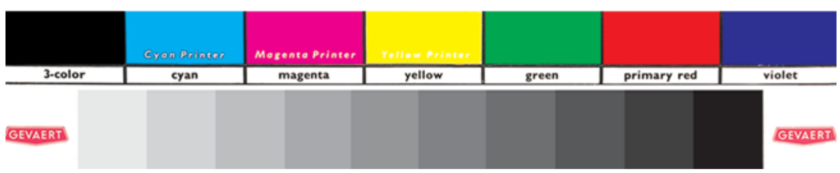
Total color difference, ΔE^*_{94}, has illustrated the least deviation of all colors when using the scanner system. Spectrophotometri analysis has shown that the lightness has primarily influenced the total color difference, ΔE^*_{94}, more than chroma and hue. As previously mentioned, the visually presentable system incorporates light and dark parts of painting. Therefore, the contrast is very important for quality reproduction. The contrast analyses have shown, on the basis of color reproduction curves (Table III), that the best reproduction is obtained with the conventional camera. The same analyses have confirmed that the objective evaluation is comparable with the subjective.

Based on the above results, one can conclude that it is necessary to take into account aesthetic criteria when making reproductions of art works which belong to the bright-shadow visually presentable system. The most important criterion for successful reproduction of this visually presentable system is lightness. The criteria obtained for successful reproduction may not be necessarily implemented in the reproduction of other visually presentable systems owing to their differing formal characteristics.

References

1. *Enciklopedija likovnih umjetnosti*, Jugoslavenski leksikografski zavod, svezak I, Zagreb, 1966. p. 636
2. M. Brozovic, Tone image transformation into the image with dominance of bright and shadow, *Acta Graphica* **9**(3), 137 (1997).
3. H. Wölfflin, *Temeljni pojmovi povijesti umjetnosti – Problem razvoja stila u novijoj umjetnosti*, Kontura i Institut za povijest umjetnosti, Zagreb, 1998, pp. 85–118.
4. E.H. Gombrich, *Reflections on the History of Art*, Phaidon, Oxford, 1987.
5. R.S. Berns, The science of digitizing two-dimensional works of art for color-accurate image archives – concepts through practice, *Munsell Color Science Laboratory Technical Report*, 2000, RIT, Rochester, NY, http://www.cis.rit.edu/research/mcsl/.
6. R.S. Berns, Direct digital imaging of Vincent van Gogh's self-portrait – A personal view, *Munsell Color Science Laboratory Technical Report*, RIT, Rochester, NY, 2000, http://www.cis.rit.edu/research/mcsl.
7. H. Kipphan, *Handbook of Printing Media*, Springer, Berlin, 2001.
8. M. Langford, *Advances in Photography*, Focal Press, Oxford, 1998.
9. B. Erickson and F. Romano, *Professional Digital Photography*, Prentice-Hall International, New York, 1999.
10. G. Field, *Color Scanning and Imaging Systems*, GATF, Pittsburg, PA, 1990.
11. ISO 3664: Viewing Conditions – for Graphic Technology and Photography, 1999.
12. M. D. Fairchild, *Color Appearance Models*, Addison-Wesley, Reading, MA, 1997.
13. G. Wyszecki and W.S. Stiles, *Color Science: Concepts and Methods, Qualitative Data and Formulae*, John Wiley and Sons, New York, 1982.
14. H. Plettenberg, *Moderne Reproduktion, Grundlagen und Techniken professioneller Bildverarbeitung mit dem Computer*, Verlag Beruf und Schule, Itzehoe, 1996.
15. A. Mortimer, *Colour Reproductions in the Printing Industry*, Pira International, Leatherhead, UK, 1991.
16. R.S. Berns, *Principles of Color Technology*, John Wiley and Sons, New York, 2000.
17. *CIE Industrial Colour Difference Evaluation*, CIE Publication 116, Vienna, 1995.
18. K. Schläpfer, *Farbmetrik in der Reproduktionstechnik und im Mehrfarbendruck*, UGRA, St. Gallen, Switzerland, 1993. p. 68.
19. I. Pavlic, *Statisticka teorija i primjena*, Tehnicka knjiga, Zagreb, 1988, pp. 151–152.

Color Plate 8(a). Mato Jurkovic: *The way to quayside*, oil on canvas 21 × 27 cm from the collected works “Miniatures from Split”, exhibited in art conservation gallery in Split, Croatia. (*Brozovic, et al.,* pp. 240–245)



Color Plate 8(b). GEVAERT Macbeth control strip. (*Brozovic, et al.,* pp. 240–245)