Applications of Human Vision Modeling Theories In Image Quality Valuation of Ink Jet Hardcopy Outputs

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Abstract

Human Visual System models (which several ones can be found in the literature) are responding to the physics and features of human eye perception features. They are based on elementary Heinemann's experience, which proved the nonlinear relation between luminance (physical luminous intensity) and brightness (subjective luminous intensity) of a tested image perceived by the HVS.

This paper presents the comparison of several HVS models applied to own designed test image with special areas for machine valuation. It presents the results of applying these models (by the histogram modification method) to the model image and analyzing values of Ink Jet hardcopy outputs comparing to the original one. After all the best HVS model is introduced and a new test algorithm to the digital valuation.

1. Introduction

One of the earliest and most commonly known problems is objective Image Quality valuation. Information written on paper is usually prepared for reading by human or machine (peripheral equipment like scanners, detectors and others). Quality of written that way information can be valued in two ways – subjectively (by human eye response) or objectively (by measuring the parameters of Image Quality due to ISO/IEC13660).

The subjective way of valuation can be controversial because of strong people individuality (different eye features). Actually only the objective way with step by step digital analysis of examined image can be credible, but - only when corresponding to the features of human eye response. It requires searching for relations between machine and eye response in models of Human Visual System. Information written on paper is appropriated for human reading or machine analyzing by various peripherals like: scanners, detectors etc. One can evaluate the quality of read information subjectively – by human eye perception – or objectively by measure Image Quality parameters (with reference to ISO/ICE13660). Comparison of these two evaluation methods can be feasible with Human Visual System (HVS) modeling theory. There are some different theories and models of HVS found in literature. One of the fundamental features of HVS is nonlinear function between luminance and brightness of observed image subjectively perceived by human eye. The Heinemann's classic experiment described in this paper is based on that relation. Presented HVS models due to analyze of human eye response were derived from Heinemann's experiment. These theories are used for transformations of model image. They are intended to give a better image quality for human analyzing. This paper includes basic information about model-based image modification techniques and results of comparing transformed images. Algorithm of comparison is presented and the best theory of human eye modeling is chosen. Nevertheless all the transformations were done on the monochromatic model it is possible to apply them to color CMYK images.

2. Human Visual System

As a Human Visual System it is generally defined the features and characteristics of human eye perception. One of the basic features of the HVS is nonlinear relation between physical luminous intensity (luminance) and perceived the subjective luminous intensity (brightness).

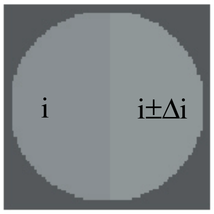


Figure 1. Illustration of Heinemann's experiment - phase.

That function is called Human Visual Curve and was primary predesignated in a classic Heinemann's experiment.

In this experiment people were shown two fields with a light patch of intensity (Fig. 1). One of the halves was randomly made either darker or brighter than the other half by a value of (Δi). It was intend to determine the minimum value of luminous difference for which the observer could correctly point the brighter or darker half. The results are shown on a graph below (Fig. 2).

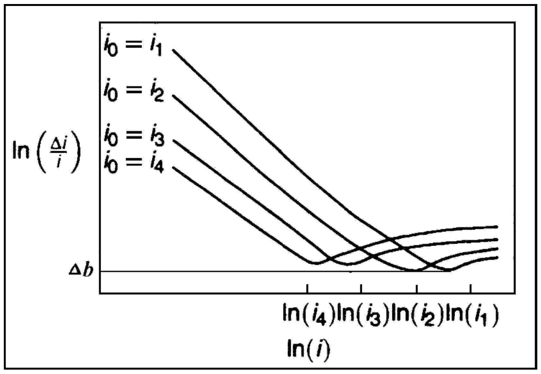


Figure 2. Human Visual Curves – luminance as a function of brightness in logarithmic scale for several different values (i_1,i_2,i_3,i_4) of average luminance of an image (i_0). As one can see, the minimal distinguishable difference of luminance is constant (Δb) and correspond to the average value of luminance that visual system is adapted for.

These curves provide measurement of the derivative of the HVS nonlinearity. In Heinemann's work Human Visual Curves were defined:

$$v(i) = \frac{di}{db}\frac{1}{i} \tag{1}$$

From this equation one obtains the HVS model function that could be used for modification of model image:

$$f(i) = \int_{i_{\min}}^{i} \frac{1}{iv(i)} di \tag{2}$$

In the literature there are several model functions that could be also used for image modification and are based on Heinemann's theory. They will be presented in 3rd chapter. Now I will handle a subject of image modification method.

2. Modification Method

One of the most common techniques of image processing is histogram modification. Several transformations for that technique have been proposed in literature and have proven particularly useful for image processing.

The general idea of histogram modification is presented on chart below (Fig. 3). The intensity of the original image is defined by the real valued function (g) whilst (i) is an intensity of the processed image. Brightness perceived by HVS after processing is denoted by (b).

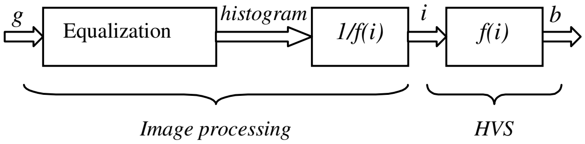


Figure 3. Model based histogram modification chart.

The original analog image with intensity (g) is subjected to the equalization and converted to the digital histogram. After that is multiplied with a inverse of model function resulting in the processed image (i). It is useful to know the histogram shape of the image for a given model function. When f(i) is strictly increasing, then the histogram of the processed image is equal to the derivative of the model function:

$$p_i(i) = \frac{df(i)}{di} \tag{3}$$

When converted in this way image is seen by a human observer the HVS transformation should cancel out previous operations causing making subjectively better or worse final results which always are dependent on used modeling theory.

3. HVS Modeling Theories

Models of HVS nonlinearity are usually chosen to fit data from psychophysiological experiments that attempt to measure the relative sensitivity of subjective brightness to image luminance. They are derived from classic Heinemann's experiment. I will now present several models that can be used for model-based histogram modification. To make the comparison of these models easier, they were all normalized.

3.1. Richter's Theory

Richter presented modified logarithmic model and given by Eq. (4):

$$f(i) = \frac{\ln(1+\frac{i}{c})}{\ln(1+\frac{1}{c})} \tag{4}$$

Where: c-parameter representing the viewing conditions and equivalent to the slope of the modified histogram.

Modeling theory based on this equation is called a histogram hyperbolization and obtained by applying Eq.(3) to the model of Eq. (4):

$$p_i(i) = \frac{1}{\ln(1+1/c)(i+c)} \tag{5}$$

3.2. Judd's Theory

Judd proposed the first model with the average luminous intensity in the visual field (i_0) as a parameter:

$$f(i) = \frac{i(1+i_0)}{i+i_0} \tag{6}$$

Unfortunately the corresponding visual characteristic curve for this model gives not as good results as the others, so it won't be further considered.

3.3. Mokrane's Theory

In proposed by Mokrane the visual characteristic curve in logarithmic scale is approximated by two line segments of slopes:

$$-\alpha_1 \text{ for } i \le i_0 \text{ and } \alpha_2 \text{ for } i > i_0 \tag{7}$$

Thus,

$$f(i) = \left\{ \begin{array}{ll} \dfrac{\alpha_2 i^{\alpha_1}}{\alpha_1 i_0^{-\alpha_2} + \alpha_2 i_0^{\alpha_1} - \alpha_1}, & i \le i_0 \\ \dfrac{\alpha_1 i_0^{-\alpha_2} + \alpha_2 i_0^{\alpha_1} - \alpha_1 i^{-\alpha_2}}{\alpha_1 i_0^{-\alpha_2} + \alpha_2 i_0^{\alpha_1} - \alpha_1}, & i > i_0 \end{array} \right\} \tag{8}$$

By applying Eq. (8) to Eq. (3), we find that the histogram of the processed image is:

$$p_i(i) = \begin{cases} \dfrac{\alpha_1 \alpha_2 i^{\alpha_1 - 1}}{\alpha_1 i_0^{-\alpha_2} + \alpha_2 i_0^{\alpha_1} - \alpha_1}, & i < i_0, \\ \dfrac{\alpha_1 \alpha_2 i^{-\alpha_2 - 1}}{\alpha_1 i_0^{-\alpha_2} + \alpha_2 i_0^{\alpha_1} - \alpha_1}, & i > i_0 \end{cases} \tag{9}$$

3.4. Modified Mokrane's Theory

Mokrane made reduce in previous model that has the disadvantage of introducing a discontinuity in the output histogram. To avoid this problem Cobra proposed modification of Mokrane's model into:

$$f(i) = \left\{ \begin{array}{ll} \dfrac{\alpha_2 i_0^{-\alpha_1} i^{\alpha_1}}{\alpha_1 + \alpha_2 - \alpha_1 i_0^{\alpha_2}}, & i \le i_0 \\ \dfrac{\alpha_1 + \alpha_2 - \alpha_1 i_0^{\alpha_2} i^{-\alpha_2}}{\alpha_1 + \alpha_2 - \alpha_1 i_0^{\alpha_2}}, & i > i_0 \end{array} \right\} \tag{10}$$

The output image histogram in modified Mokrane transformation then:

$$p_i(i) = \begin{cases} \dfrac{\alpha_1 \alpha_2 i_0^{-\alpha_1} i^{\alpha_1 - 1}}{\alpha_1 + \alpha_2 - \alpha_1 i_0^{\alpha_2}}, & i \le i_0 \\ \dfrac{\alpha_1 \alpha_2 i_0^{\alpha_2} i^{-\alpha_2 - 1}}{\alpha_1 + \alpha_2 - \alpha_1 i_0^{\alpha_2}}, & i > i_0 \end{cases} \tag{11}$$

3.5. Cobra's Theory

Cobra derived his formula empirically corresponding to Heinemann's experimental curves. In this model, given by Eq. (12), the characteristic curve in logarithmic scale tends to asymptotes for $i \ll i_0$ (slope of this asymptote is α_1) and $i \gg i_0$ (slope α_2). Parameter β controls the transition from one asymptote to another.

$$f(i) = \frac{a i^{\alpha_1} \left[\left(i^\beta + i_0^\beta \right)^{\frac{\alpha_2}{\beta}} - d \right]}{\left(i^\beta + i_0^\beta \right)^{\frac{(\alpha_1 + \alpha_2)}{\beta}}} \tag{12}$$

Where:

$$a = \frac{(1 + i_0^\beta)^{(\alpha_1 + \alpha_2)/\beta}}{(1 + i_0^\beta)^{\alpha_2/\beta} - d} \tag{13}$$

And:

$$d = \frac{\alpha_1 i_0^{\alpha_2 2\alpha_2/\beta} (\beta - \alpha_1)}{\beta(\alpha_1 + \alpha_2) - (\alpha_1 - \alpha_2)^2} \tag{14}$$

The corresponding histogram may be obtained by applying Eq.(10) to Eq.(3):

$$p_i(i) = \frac{a i^{\alpha_1 - 1} [\alpha_1 i_0^\beta (i^\beta + i_0^\beta)^{\alpha_2/\beta} - d(\alpha_1 i_0^\beta - \alpha_2 i^\beta)}{(i^\beta + i_0^\beta)^{(\alpha_1 + \alpha_2)/\beta + 1}} \tag{15}$$

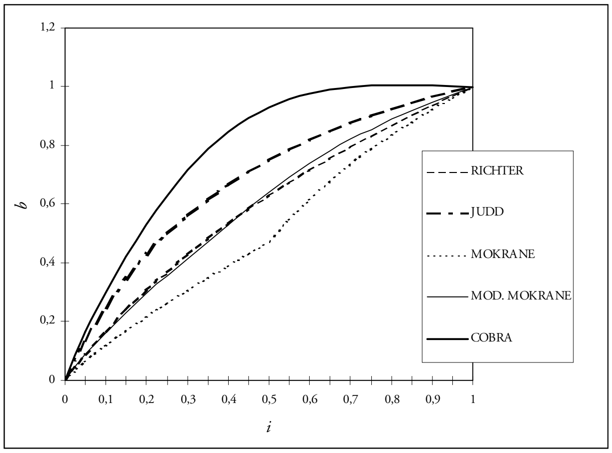


Figure 4. Model functions comparing diagram.

A diagram below shows the difference between discussed model functions (Fig. 4).

Values of applied parameters for a comparing chart: for Richter's model c=0,5 and for other models i_0=0,5 (following the assumption that the middle gray level of the output image matches the average intensity in the whole visual field). The value used for other parameters were: α_1=0.85, α_2=0.15, β=3 – measured from the graphics of Heinemann's experiment.

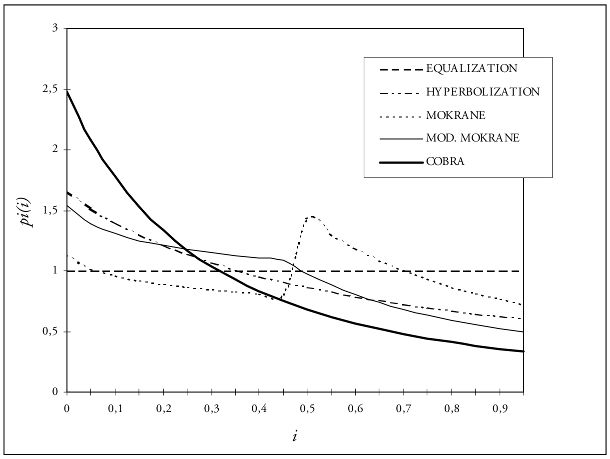


Figure 5. Histogram processing functions.

A different shape of these curves resulting in different image transformation results. Application of these processing functions completed on Fig.5 to the original image will be shown on an example in next chapter of this paper. But first I'll discuss the image quality valuation algorithm based on HVS modeling theories.

4. Image Quality Valuation Algorithm

Applying human vision modeling theories to the valuation process of ink jet hardcopy outputs one must follow the specified algorithm (Fig. 6).

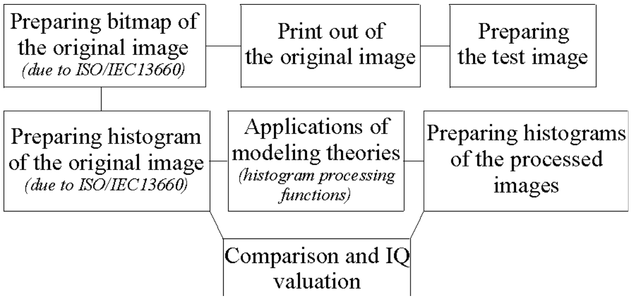
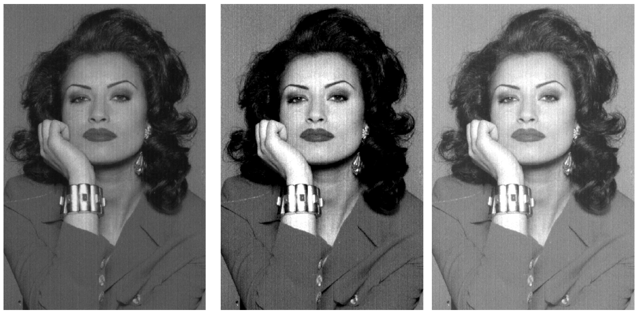


Figure 6. Image quality (IQ) valuation algorithm based on human vision modeling theories.

The most important is correctly prepared test image. Due to the ISO/IEC13660 there should be several special areas for measuring print quality parameters, whilst it should include objects for the subjective valuation too. There should be areas for checking the print out precision given by the printer what is very important to analyze the influence on the final results – resolution, background haze, blurriness, blob attributes etc. To check color proof (by measuring Lab ΔE parameter) there should be also concrete Lab (CMYK) value areas. To have a possibility of making image-processing characteristics through another image-based theories, there should also monochromatic percentage included etc.

Prepared test image is converted into original histogram (Fig.6) and after that transformed by histogram processing functions to the model-based histograms. At this phase it is possible to make first objective valuation by comparing the histograms and it's parameters like average, standard deviation, median etc. Now it is possible to get final images that will be helpful to measure print parameters due to ISO/IEC13660 and to the subjective valuation. Simple example is presented on pictures below.

5. Example



Original *Hyperbolization* *Mokrane*

Mod. Mokrane *Cobra* *Equalization*

Figure 7. Example of model-based image processed picture

As a simple example of model-based transformations I have prepared picture of a woman processed through an algorithm (Fig. 7). As it is easy to see – original image has got lowest brightness and intensity (average luminance i_0=86 at 256 scale) than others. Hyperbolization gives good brightness and image is lighter than the basic one (i_0=99). Mokrane is even lighter, but has worse contrast (i_0=133). Modyficated Mokrane technique looks much better – many details are easier to recognize in darker and lighter areas (i_0=129) and Cobra is close to that too (i_0=124).

To make sure, that presented results aren't accidental, this set of images I have printed on three different quality printers: 1st - Tektronix's Phaser 850DP, 2nd - HP2500CM and 3rd – HP2000P. Print outs were given to the subjective estimation to a hundred people. Most of the people choose the Cobra's model as a best quality processing theory. Results are shown on a chart below (Fig.8):

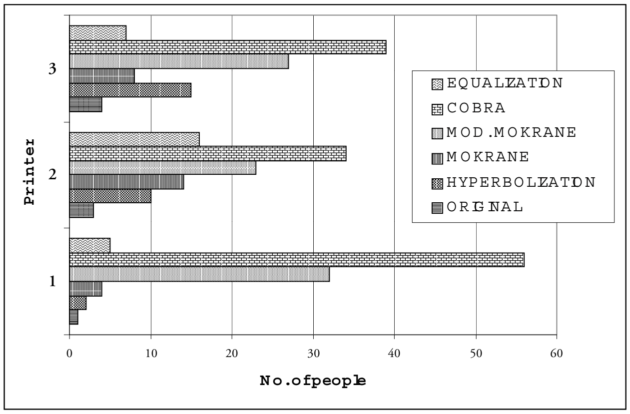


Figure 8. Statistic chart of valuation of ink jet hardcopy outputs made by a hundred subjective observers.

6. Conclusion

In other studies and cases of image quality valuation it was also proved that Cobra's model is one of the best theories describing human eye perception characteristics. Statistically subjective visual effect is also best of all presented theories. That means that this model is really close to the HVS characteristics and provides better subjective quality of observed images.

It should be pointed that as with the most image enhancement techniques the resulting image quality depends on the specific image being processed and usually it is difficult to predict beforehand for what types of images the technique will work best. There is also possibility to find that kind of image that provide the other model better effect than Cobra's one.

Nevertheless this paper is focus on monochromatic print outs, the results and techniques described in it could be also applied to the processing of color image samples made in CMYK technique.

This work has a wide range of application to the image quality valuation where image hardcopies are destined for a human observer.

7. References

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Biography

Arkadiusz Pietrzak received his electronic engineering degree from the Warsaw University of Technology, Poland, in 2001, his technician diploma in electronics from the Technician Electronics secondary school, Poland in 1995. Currently he is studying at postgraduate in Warsaw University of Technology in Poland. Main area of his research is digital signal processing and its applications to image transformation and digital image processing and conversion.