Image Processing Method for Colour Image Preference

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Bildverarbeitungsmethode
zur bevorzugten Erscheinung
von digitalen Farbbildern

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Colour image preference- previous studies

- Young observers, elderly observers
- Bottom-up methodology
  - measuring basic HVS properties
    - CSFs
    - optical density changes in the crystalline lens
    - but higher mechanisms are involved
  - Results not applicable to display optimization directly

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Colour image preference- present work

- Top-down methodology
  - preference differences using spatially *complex* stimuli
  - photorealistic images
    - global and local contrast
    - white point
    - average chroma
    - image colorization
  - insufficient to reconstruct the early vision properties of young adults for elderly observers to model image *preference* differences among the age groups

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Classic image quality metrics

- Image quality was often formulated with respect to a reference image
  - S-CIELAB, iCAM, ...
- based on a metric in the image space
- using models of the human visual system
- or a similarity-based approach
  - taking the direction of image distortion into account

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No-reference image quality assignment and enhancement

- through user preference data
- virtual „reference image”: a cognitive „ideal” representation of the input image
- image enhancement algorithm
  - a set of color image processing transformations to enhance the input image without a real reference image
  - to approximate a virtual „most preferred image” of the scene depicted in the input image
  - with respect to the age of the user

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Image transforms – present work

- 4 of 11 transforms turned out to be relevant to enhance colour image preference
- modifying the 3 perceptual correlates of CIECAM02: *J*, *C* and *h*
- the 4th transform modifies the white point of the image

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The LE transform (*J*- transform)

- LE: a local lightness contrast enhancement (sharpness / blur)
  - Wallis-filter,applied pixelwise on the entire image
- For the *ij*th pixel:

$$J'_{i,j} = \left(J_{i,j} - m_{i,j}\right) \cdot p + m_{i,j} \qquad m_{i,j} = \frac{1}{\left(2 \cdot w + 1\right)^2} \cdot \sum_{k=i-w}^{i+w} \sum_{l=j-w}^{j+w} J_{k,l}$$

$p<1$: blur, $p>1$: sharpening, $p=1$: intact

w denotes the radius of the convolution window in which m_{ij} was calculated

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The TC transform (*J*- transform)

- TC (tone curve):global contrast enhancement algorithm
  - modifies the *J* value of all pixels in the image, according to a sigmoid function f_{TC} ($J'_{ij} = f_{TC}(J_{ij})$)
  - f_{TC} is a continuous Bézier spline with 4 control points
    - this results in higher lightness for light colors and darker lightness for dark colors - compared to the mid tones
    - enhances the global contrast of the input image

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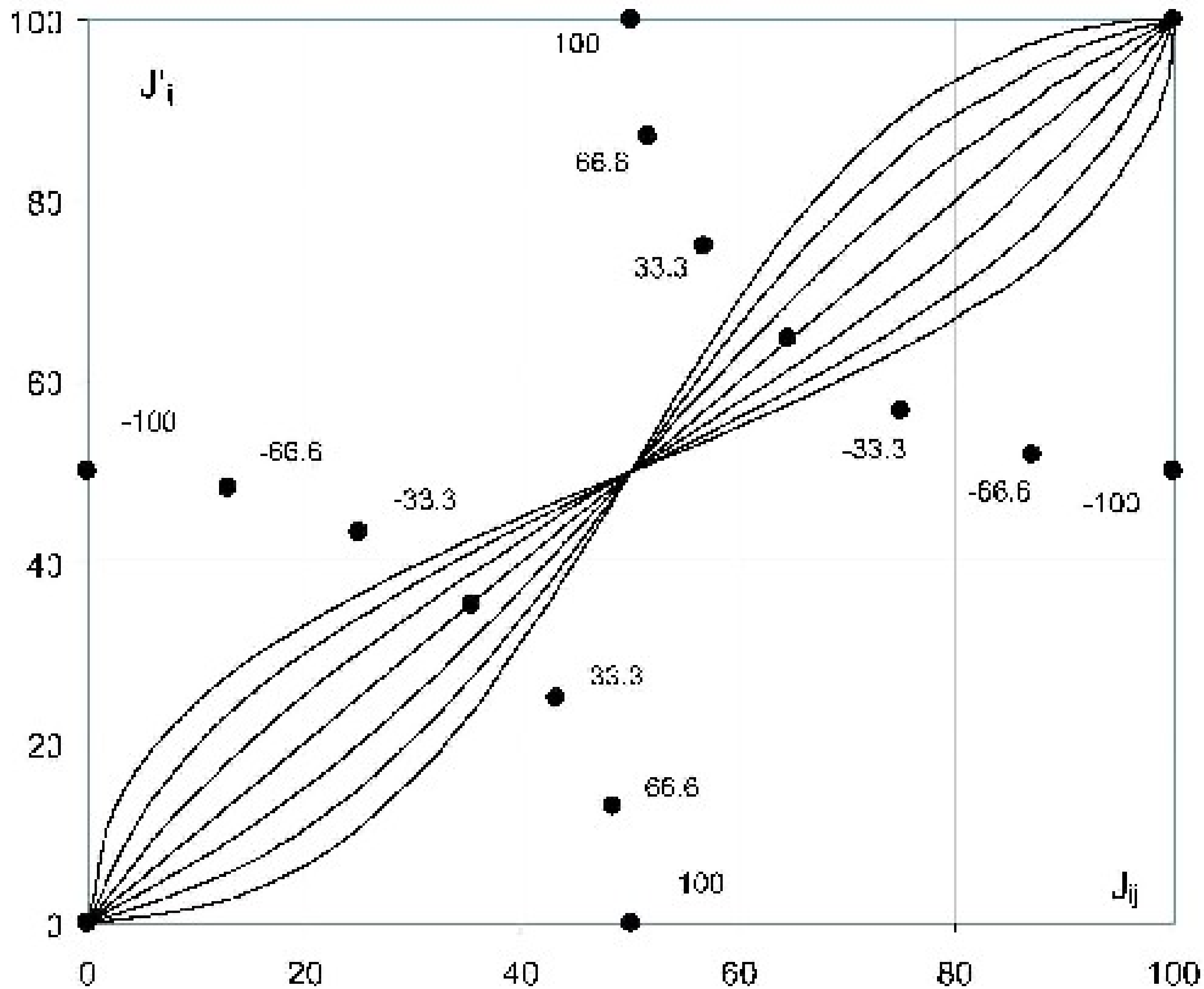
The TC transform (*J*- transform)



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CH (*C*- transform)

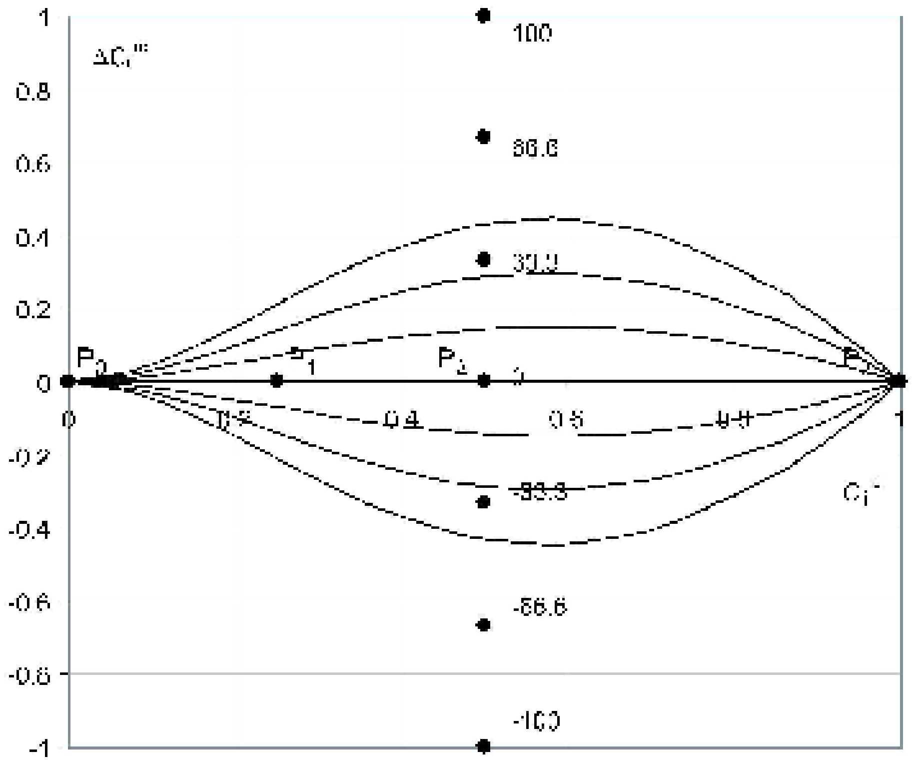
- CH:*hue-dependent chroma* boost
- increases/decreases the CIECAM02 *C* correlate with different amounts of chroma change in different *h* ranges
- Chroma values (C_{ij}) of a pixel were increased or decreased by ΔC_{rel} ($C_{rel\,ij}' = C_{ij\,rel} + \Delta C_{ijrel}$)

CH (*C*- transform)

- ΔC_{rel} was computed by a Bézier spline function if the hue of the pixel was in a given hue interval
- The value of ΔC_{rel} depended on the value of $C_{\mathrm{ij,rel}}$
  - a relative chroma related to the maximum displayable chroma ($C_{\mathrm{max,ij}}$) for J_{ij} and h_{ij}.

CH (*C*- transform)

- The input parameter of the CH algorithm was c_1
- c_1 stands for the overall magnitude of ΔC
  - this is the height of control point *P*2.



CH (*C*- transform)

- Idea of ΔC_{rel}:
  - nearly achromatic colors were given their original values (no chroma change)
  - pixels with higher C_{ij} values were boosted
  - but carefully in order not to generate out-of-gamut colors

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CH (*C*- transform)

- CH applies different amounts of chroma enhancement in each segment of the hue categories (in each hue interval)
- From red, orange, yellow, green, cyan, blue, purple, skin, sky, grass and foliage, only the following hue ranges turned out to be significant: red, yellow, green (and thus grass and foliage), blue, as well as skin and sky
- Long term memory colors and focal colors from literature

CH (*C*- transform): hue intervals

i=	0 (blue)	1 (green)	2 (red)	3 (skin)	4 (sky)	5 (yellow)
h_{min}	219.21	127.13	344.49	37.58	213.53	72.54
h_{max}	273.18	182.57	37.61	77.58	253.53	127.13

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WP (CCT- transform)

- The white point of an image is set to a desired CCT value using the CIECAM02 Color Appearance Model
- The input parameter is the target white point (W) in Kelvins.
  - From this white point, the CIE1934XYZ tristimulus values were calculated.
  - A gamut compression method is included to avoid those pixels falling off the gamut of the display.

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WP (CCT- transform)

$$\begin{bmatrix}R\\G\\B\end{bmatrix} \xrightarrow{CRT\ \text{model}} \begin{bmatrix}X\\Y\\Z\end{bmatrix} \xrightarrow[CIECAM02]{D65} \begin{bmatrix}J\\C\\h\end{bmatrix} \xrightarrow[(CIECAM02)^{-1}]{W} \begin{bmatrix}X\\Y\\Z\end{bmatrix} \xrightarrow{CRT\ \text{model}} \begin{bmatrix}R\\G\\B\end{bmatrix}$$

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Visual experiments on color image preference

- Eight elderly (average age: 69.1) and five young (average age: 25.8) color normal observers (males and females)
- Method of pair comparisons
- Thurstone’s method of pair comparison
  - color image preference z-scores
  - meaning of the magnitude of the preference z-scores
  - a low z-score indicates indifference and a high z-score indicates self-confidence

Visual experiments on color image preference

- Presenting pairs selected form the set of original and transformed versions of a set of test images
  - Only one image appeared on the screen and the observer was able to switch between the two images of a pair by pressing a button
    - No time limit was established upon observation
    - The observer was allowed to switch between the two images unlimited times
    - Observers were not instructed on how to determine the preferred image
      - They were allowed to use any criterion they felt appropriate.

Visual experiments on color image preference

- All image processing transforms were designed so that the amplitude or "strength" of their effect was characterized by a *single scalar value* as a parameter
- Preference z-scores can be depicted as a function of this parameter
- 12 original images of different scenes
  - landscapes, artificial and natural surroundings, faces and indoor photos

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Visual experiments on color image preference – general result

- Elderly group: lower *z*-scores
- Aged observers are inconsequent in their colour image preference judgments than young observers
- The mean *z*-score of the young was almost twice as much as that of the elderly: 1.400 vs. 0.7884.

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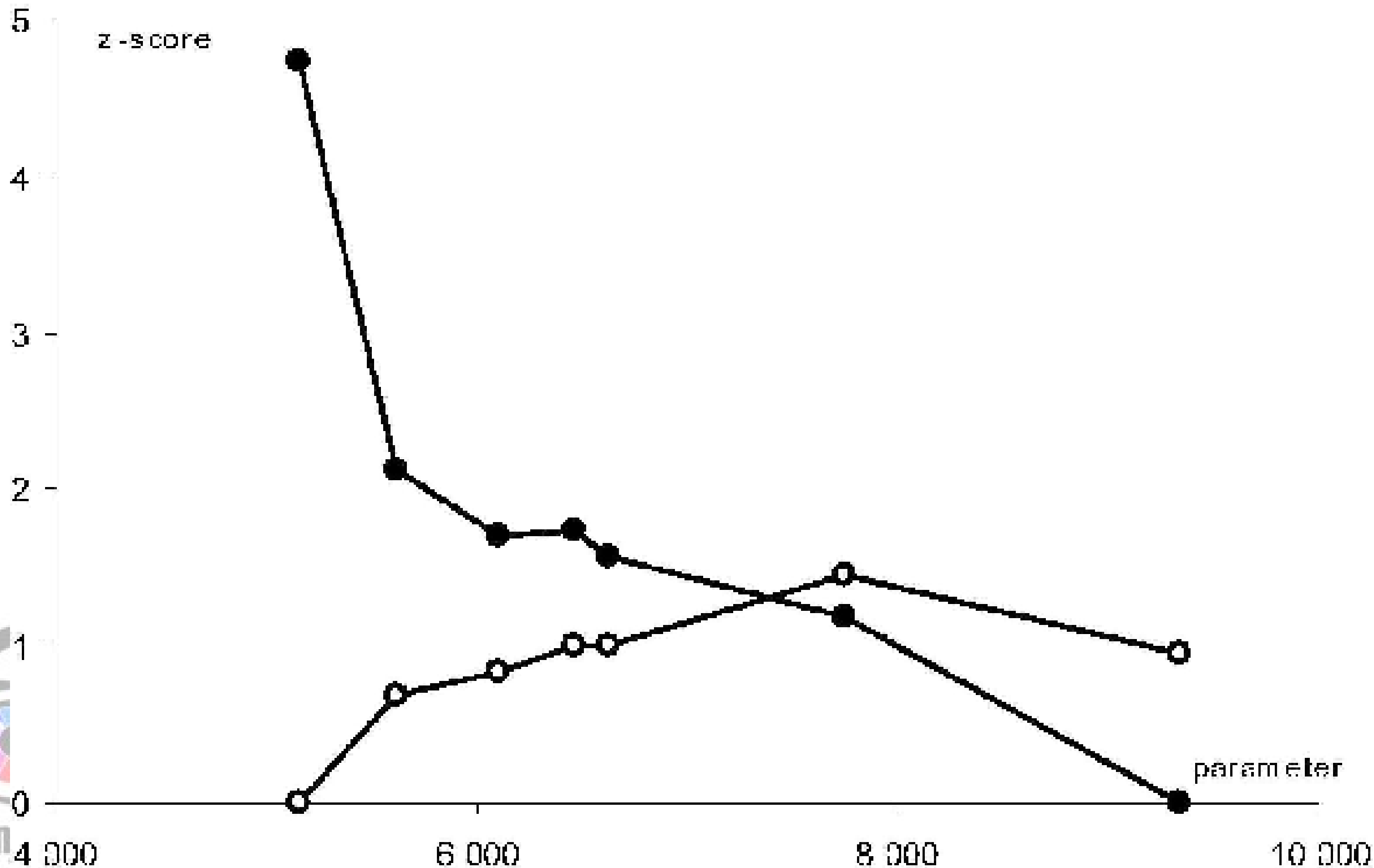
Visual experiments on color image preference – WP result

- The *z*-scores of the images were averaged for the observers, thus, for each image, a mean observer preference curve was established for the different transformed versions of the image
- *z* as a function of *p*
- *p* is the parameters of the transform
- For WP, *p*=CCT was varied between 3000K and 46000 K
- Solid symbols: elderly, open symbols: young

Visual experiments on color image preference – WP result (example – 1 image only)



Visual experiments on color image preference – WP result – optimum parameter value

*P*opt was calculated from the preference curve by weighting the investigated parameter values *P*i by the corresponding z-scores (mean values for all observers)

The value of *P*opt expresses “optimum preference” in the sense that this computing method takes into account the entire curve as opposed to simply taking the maximum of the curve:

$$P_{opt} = \frac{\sum_i z_i P_i}{\sum_i z_i}$$

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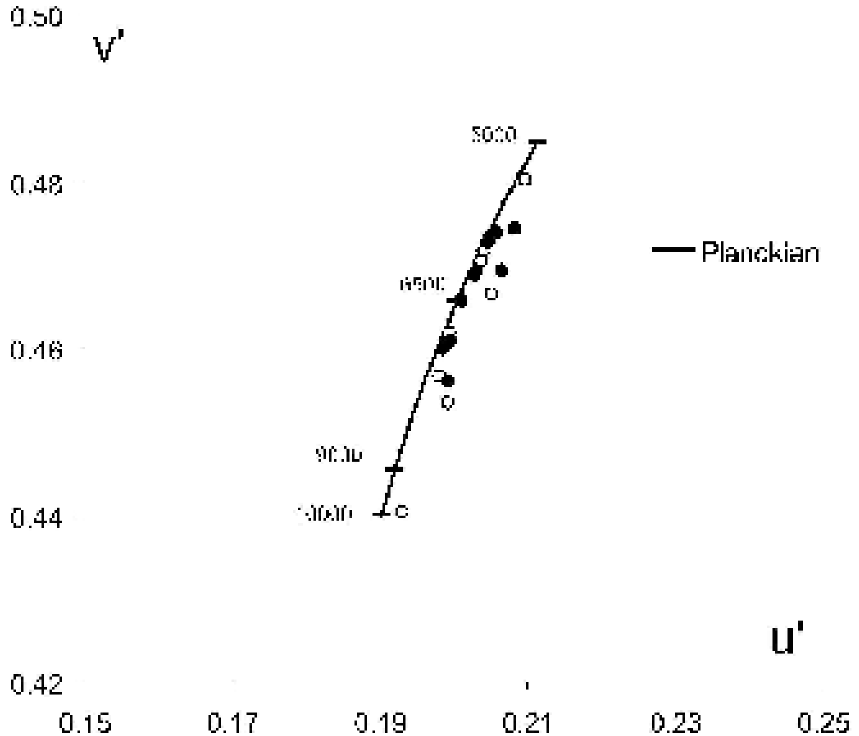
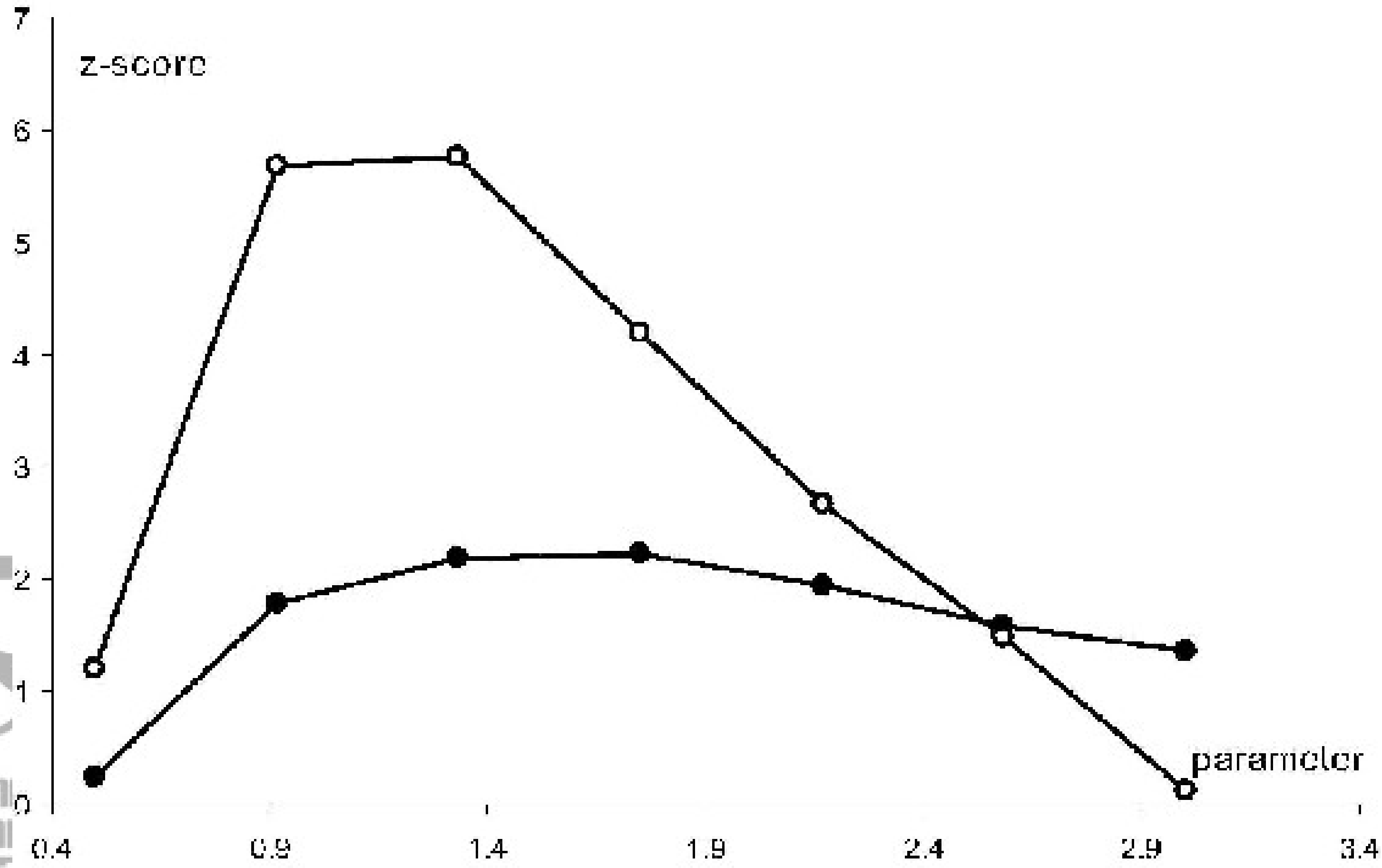
Visual experiments on color image preference – WP result –image content

- Image content had a strong effect for both aged and young observers on the preferred white point
- Lower CCT preference of aged observers



Visual experiments on color image preference – LE result

- For LE, the preference curves were averaged among the test images, p=1: original image



Visual experiments on color image preference – LE result

- Young observers
  - dislike any local lightness contrast enhancement above 1.33 independent of the image content.
- Aged observers
  - prefer a slight local contrast enhancement depending on the image content
    - If the original image contains many details of high spatial frequencies then aged observers tend to prefer higher local lightness contrast enhancement parameter values.
      - Faces, skin and noise seem to inhibit the preference of contrast enhancement. In the typical skin images neither age group preferred a harsh local contrast enhancement.

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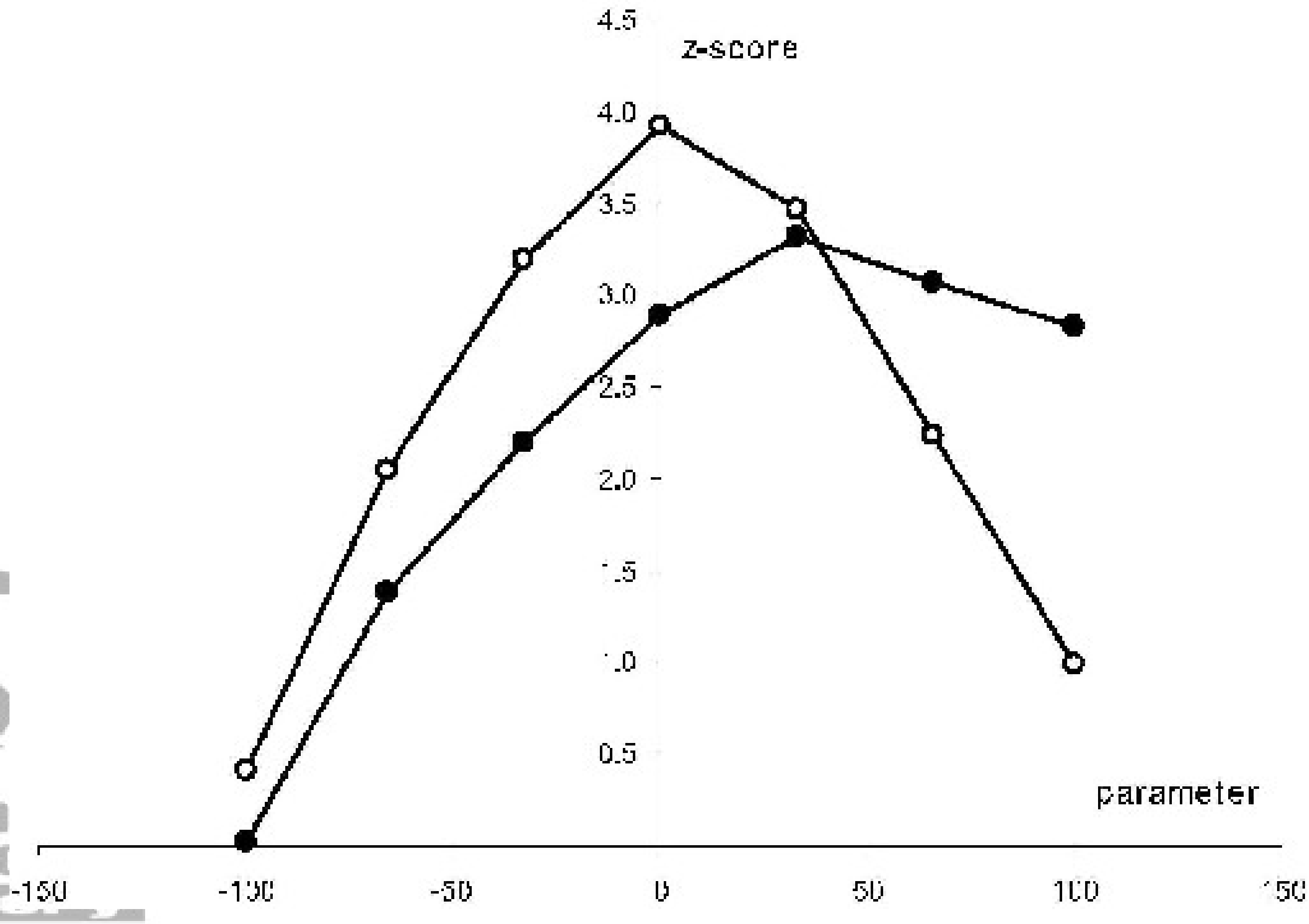
Visual experiments on color image preference – TC result

- For TC, the preference curves were averaged among the test images, p=1: original image



Visual experiments on color image preference – TC result

- Young observers
  - prefer a slight positive image enhancement parameter value
- Aged observers
  - prefer a large positive value
  - TC renders dark shades deeper, and highlights lighter
    - dynamic ranges of these regions shrink
    - the image loses fine spatial details in its dark and light regions
    - Young observers: importance of fine details in every tone region
    - Elderly observers: more unconcerned with such fine details and they prefer more global contrast

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Visual experiments on color image preference – CH result

- Each of the significant 6 hue ranges (red, green, yellow, blue, skin, and sky) was represented by 7 test images that contained many pixels in the corresponding hue range
- Both observer groups prefer chroma enhancement up to a specific level of chroma
- The *C*-course of the preference curves depends on the main hue range of the main object depicted (red, yellow, green, blue, skin, or sky) and on the observer's age

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CH result (hue dependent chroma enhancement)

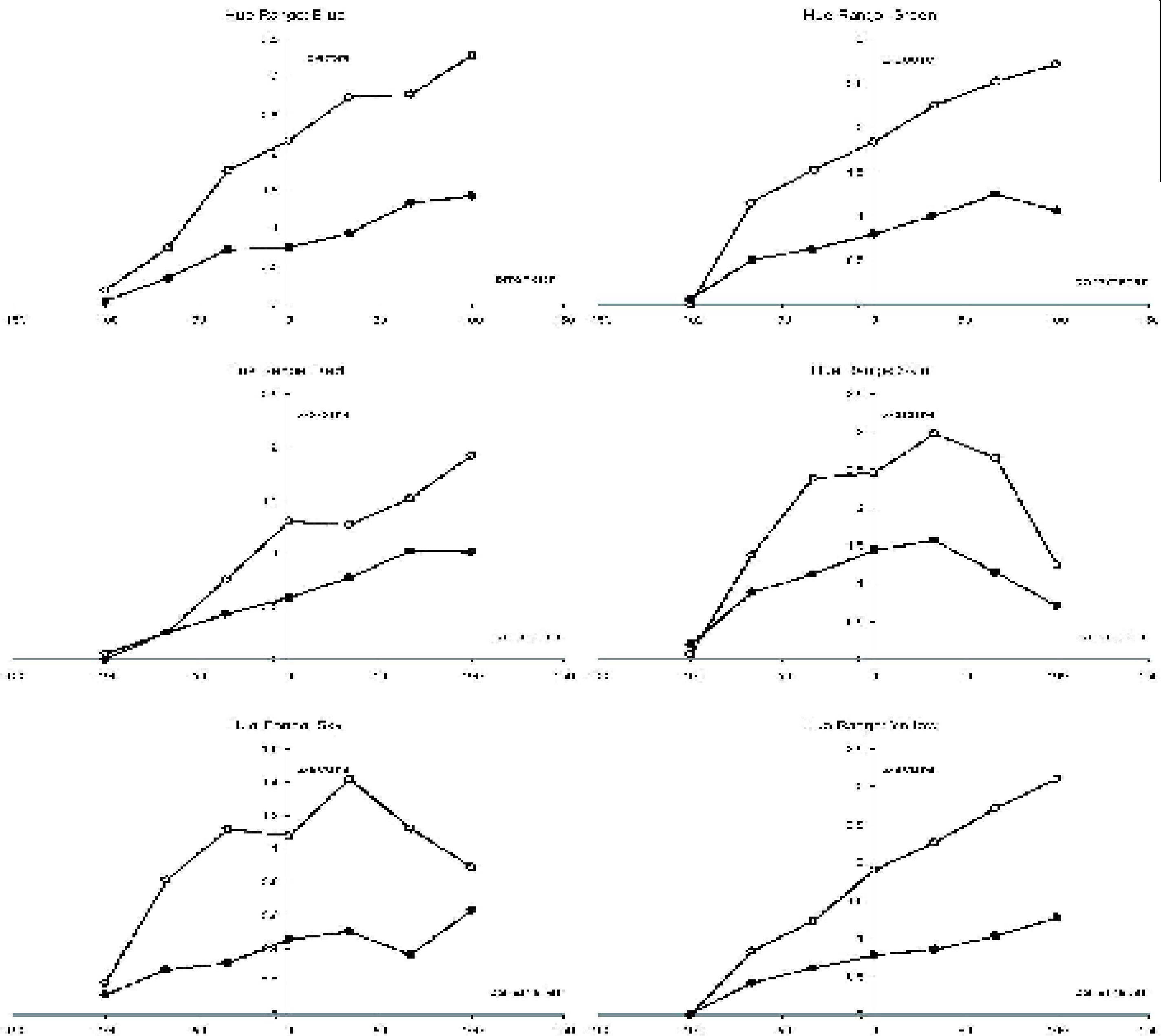

Image Processing Method

- Image enhancement algorithm for young and elderly observers
- Based on the obtained visual colour image preference curves
- Implemented in a computer program written in C++

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Image Processing Method

- Starting point: the set of image processing *transforms* (WP, LE, TC, CH)
- The input image is modified so that it will be preferred to the original
- With different constants for aged and for young observers.
- Key points:
  - 1. the maximum of the preference curve (*z* vs. *p*) is approximated from an image descriptor computed from the input image
  - 2. the amount of transform is computed to achieve this maximum

Image Processing Method

- The amount of color image enhancement to achieve the most preferred color image depends on the pictorial content and measurable quantities of the input image itself
- Stochastic dependence suitable to predict the preferred parameters of the image processing transform for any input image to get its preferred output version
  - But for WP, only a very simple model was used
    - transforming the original image to the most preferred white point of the two age groups, 7430 K for elderly observers and 7626 K for young observers.

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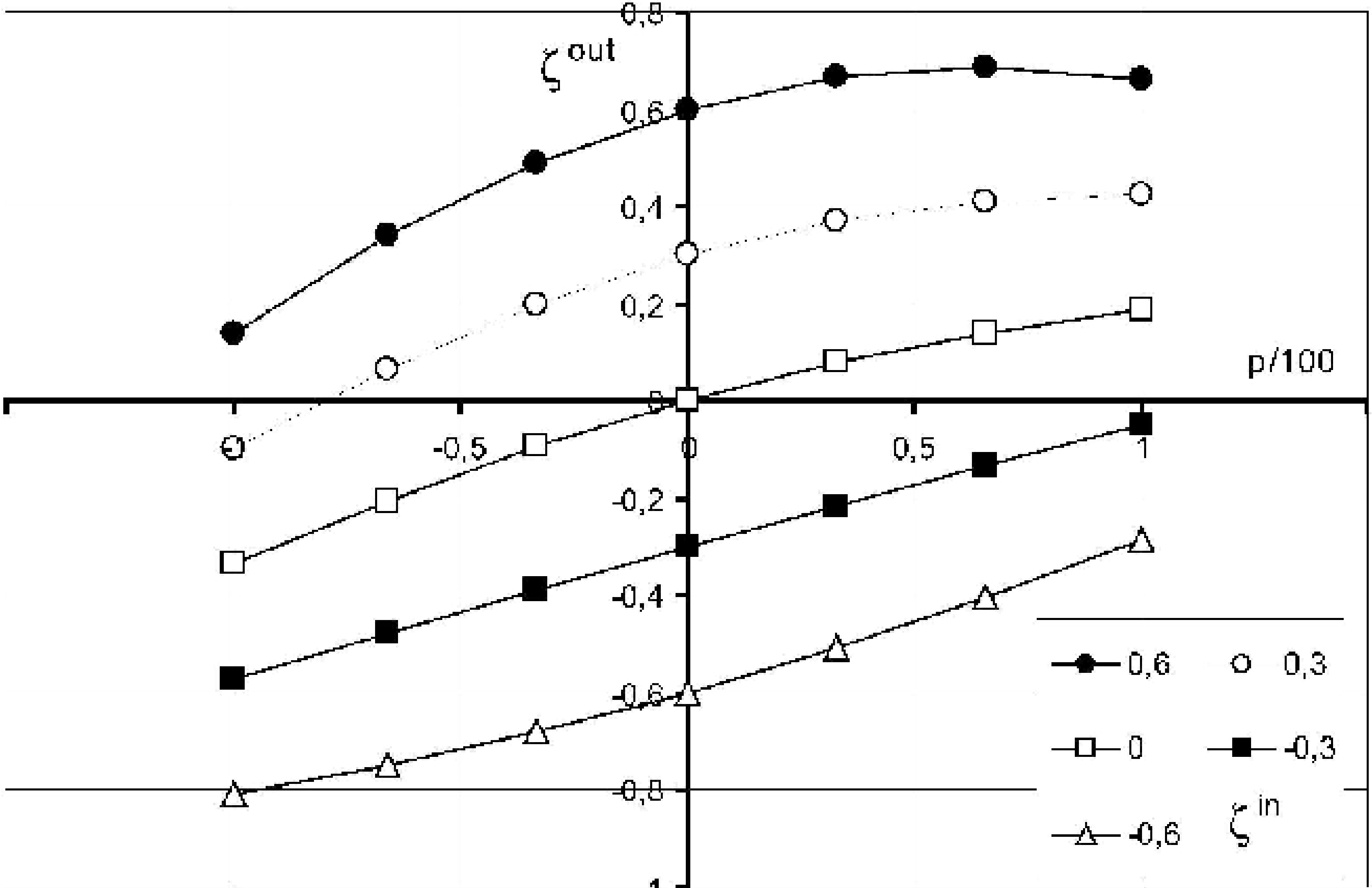
Image Processing Method

- For LE, TC, and CH, the following method is introduced:
- (1) A *descriptor* ζ was defined for the input image. The value of ζ changes as the transform is applied to the input image. The change of the descriptor characterizes the effect of the transform.
- The output value of the descriptor (ζ^{out}) depends on the value of the parameter *p* and on ζ^{inp}
- This is the descriptor input-output function, example: TC

Descriptor I/O function: (p, ζ^{inp})$\rightarrow$$\zeta^{out}$



„Ideal descriptor" function: $\zeta^{inp} \rightarrow \zeta^{opt}$

- (2) From the experimental preference curves, the optimum value of the descriptor ζ^{opt} is calculated for each test image, and this is approximated for all images, as a function of ζ^{inp}, and this is the *ideal descriptor* function.
- The optimum parameter value p^{opt} is calculated to get $\zeta^{out} = \zeta^{opt}$

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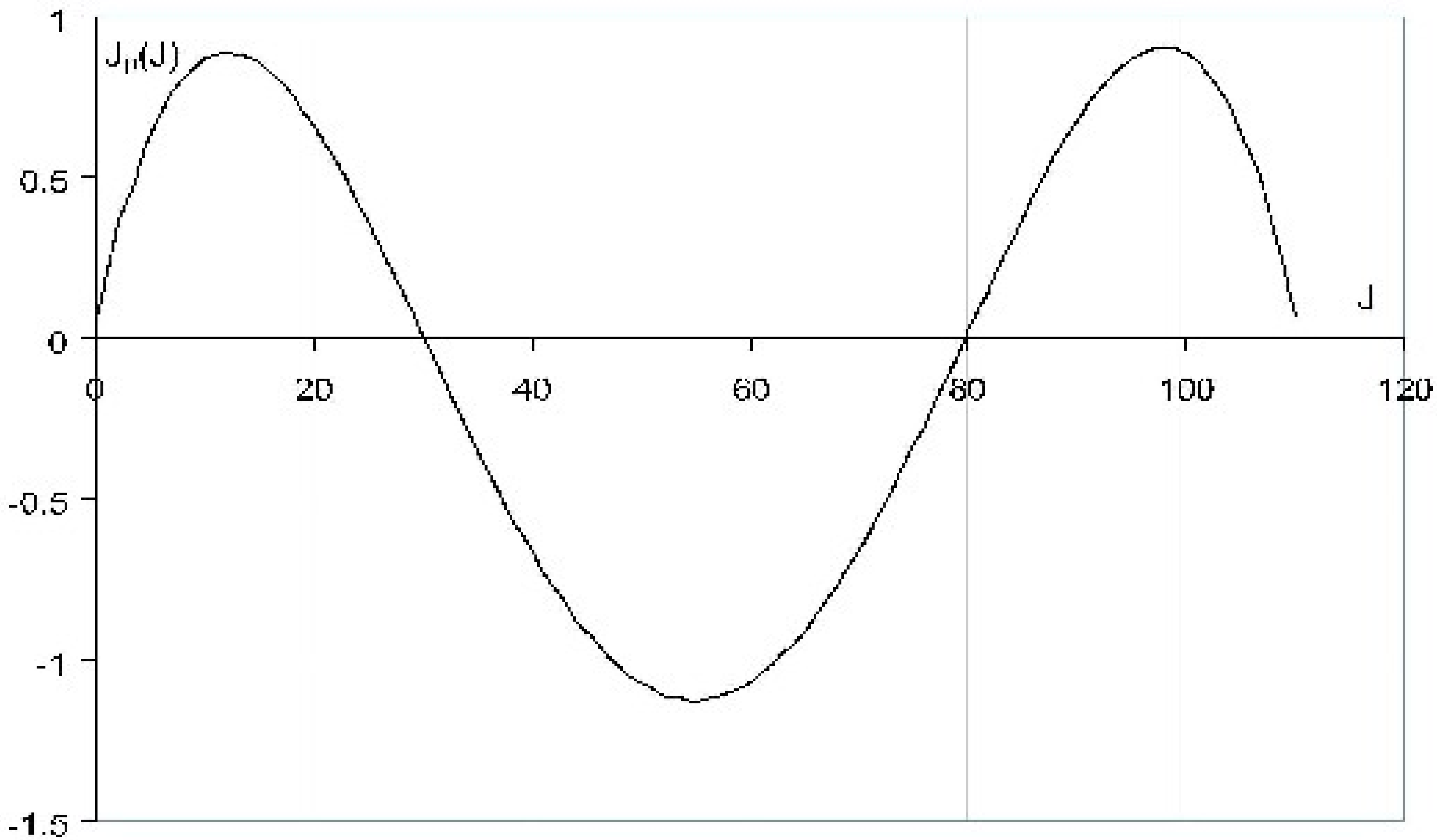
Example: TC algorithm

- The descriptor ζ_{TC} is the weighted sum of the *J*-histogram *H*(*J*) of the image
- The weights are computed with a 4-deg. polynomial
  - positive at the extremities of the *J* scale i.e. at the lower and upper fourth of the 0-110 scale
  - negative for mid-tones
    - If the input image contains many pixels in the extremities then the value of the descriptor will be positive but if mid-tones dominate then it will be negative

J-histogram-weighting polynomial to compute ζ^{TC}



TC algorithm

$$\zeta_{TC} = \sum_{0}^{J_{\max}} \overline{H}(J)\, J_p(J) \qquad \overline{H}(J) = \frac{H(J)}{\sum_{0}^{J_{\max}} H(J)}$$

Descriptor I/O function:

$$\zeta_{TC}^{out} = \zeta_{TC}^{out}\left(p, \zeta_{TC}^{inp}\right) = a\left(\frac{p}{100}\right)^2 + b\left(\frac{p}{100}\right) + c$$

$$a = -0.2115\zeta_{TC}^{inp} - 0.0743$$

$$b = 0.2618$$

$$c = \zeta_{TC}^{inp}$$

„Ideal descriptor" function :

$$\zeta_{TC}^{opt.}\left(\zeta_{TC}^{inp.}\right) \cong \begin{cases} 0.9267\zeta_{TC}^{inp.} + 0.044 \text{ for the aged} \\ 0,909\zeta_{TC}^{inp.} + 0.0027 \text{ for the young} \end{cases}$$

LE algorithm

$$f(r) = \oint_{f_x^2 + f_y^2 = r^2} \left| \Phi\left(f_x, f_y\right) \right| ds$$

$$\zeta_{LE} = \int_0^{\infty} r f(r)\, dr$$

ζ_{LE} = Dominating spatial frequency of the input image

Descriptor I/O function:

$$\zeta_{LE}^{out}(p) \cong a \ln(p) + b, \quad \left(a = a\left(\zeta_{LE}^{inp.}\right),\ b = b\left(\zeta_{LE}^{inp.}\right) \right)$$

$$a \cong -0.0621\left(\zeta_{LE}^{inp.}\right)^2 + 0.885\zeta_{LE}^{inp.} - 1.9868$$

$$b \cong 0.9643\zeta_{LE}^{inp.} + 0.197$$

„Ideal descriptor” function :

$$\zeta_{LE}^{opt.}\left(\zeta_{LE}^{inp.}\right) \cong \begin{cases} 1.0260\zeta_{LE}^{inp.} + 0.2393 \text{ for the aged} \\ 0.9793\zeta_{LE}^{inp.} + 0.4255 \text{ for the young} \end{cases}$$

CH algorithm

ζ_{CH} = Mean chroma (in the given hue range) of the image

Descriptor I/O function: $\zeta_{CH,i} = a_i\left(p_i - 100\right) + b_i$

$$a_i = 0.0011\zeta_{CH,i}^{inp} + 0.0415$$

$$b_i = 0.8751\zeta_{CH,i}^{inp} - 3.1302$$

„Ideal descriptor" function :

$$\zeta_{CH,i}^{opt.}\left(\zeta_{CH,i}^{inp.}\right) \cong \begin{cases} \alpha_i^{aged}\zeta_{CH,i}^{inp.} + \beta_i^{aged} & \text{for the aged} \\ \alpha_i^{young}\zeta_{CH,i}^{inp.} + \alpha_i^{young} & \text{for the young} \end{cases}$$

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CH algorithm

„Ideal descriptor" function coefficients in the different hue ranges:

i=	0 (blue)	1 (green)	2 (red)	3 (skin)	4 (sky)	5 (yellow)
αiY	1.05	0.90	1.18	0.68	0.83	0.97
βiY	1.73	5.68	-6.87	6.81	6.47	3.90
αiA	1.12	0.94	1.02	0.84	0.87	0.95
βiA	0.62	4.51	3.36	4.00	3.87	4.04

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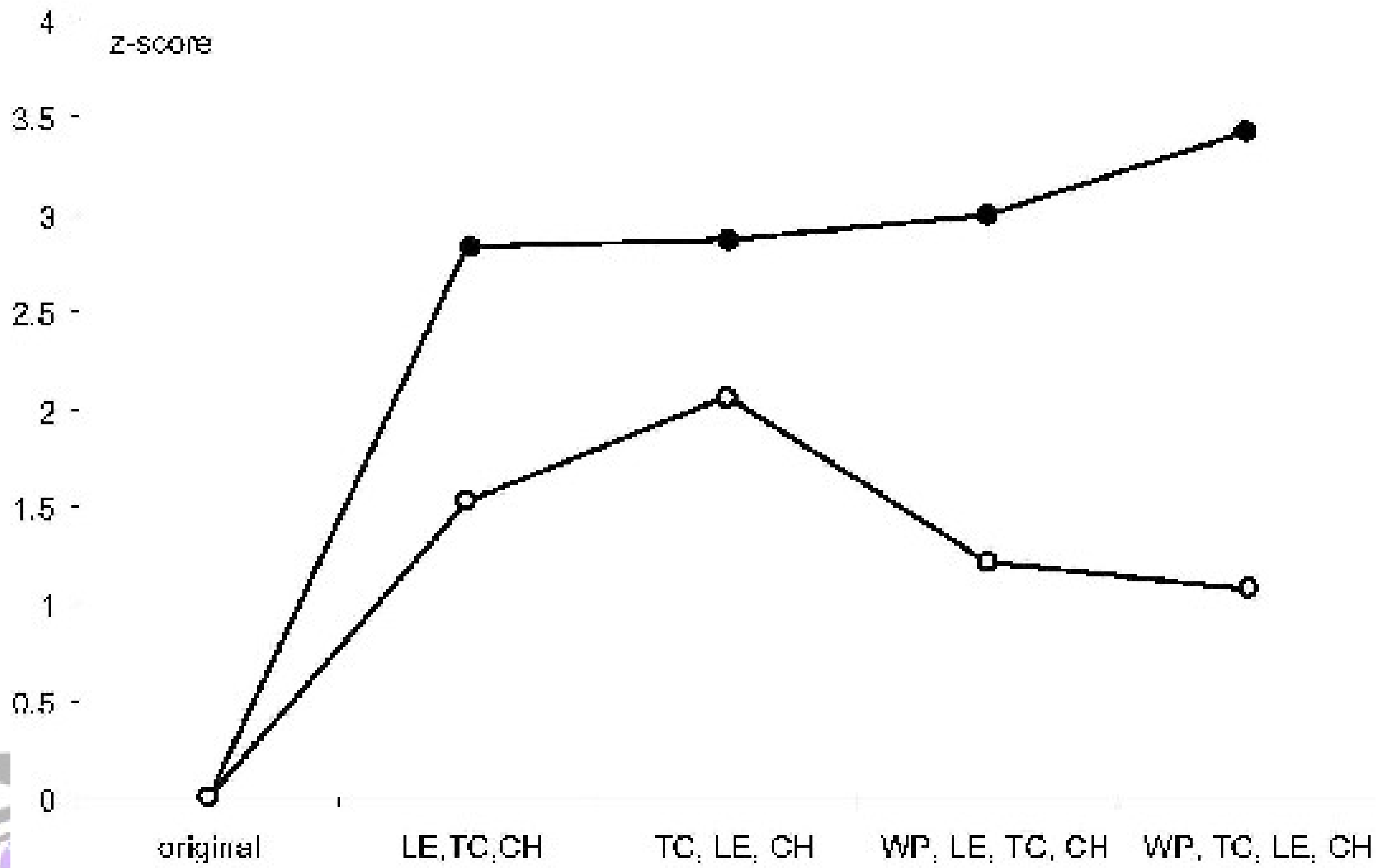
Verifying the method

- A subsequent series of visual preference experiments
- Is the enhanced image more preferred than the input image?
- What order the transforms (WP, LE, TC, CH) should be applied?
- 4 test images, 4 aged and 4 young subjects and 4 transform combinations

Verification of the method



Verifying the method

- Both age groups preferred the enhanced images over the originals.
- Aged observers preferred the transformations to be done in the following order: WP, TC, LE, CH.
- Young observers preferred TC, LE, CH, with no white point transform.
  - Studying the interaction of the different transforms concerning colour image preference is currently underway.

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Conclusions

- Colour image preference dataset
  - Local contrast, tone curve, hue range dependent chroma enhancement and white point transform
  - Different preference for young and elderly observers
- Image Processing Method
  - Without any reference image
    - The most preferred version of the input image is appoximated from the input image itself

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