Algorithm to Enhance Simultaneous Lightness Contrast in the Spatial Domain

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Outline

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Introduction

Introduction

- The visual perception of the eye is generally regarded as the most important factor for the ability of the eye for seeing objects.
- The difference in these signals coming from objects and their immediate surroundings, allows the detection of these objects. This is termed as simultaneous contrast.
- Simultaneous lightness contrast refers to the perceived enhancement of differences in the lightness signal. [Castleman, 1994].
- One of the main problems in the cross-media reproduction is the reproduction of an image in a different medium which often differ in the luminance range of that of the original.
- The difference in the luminance range causes loss of details and contrast in the limited luminance range.
- The key is not to try and reconstruct everything exactly but to consider how the images are perceived [Braun & Fairchild, 1999].

Introduction

- Two major rescaling of lightness .
- First is based on the lightness range of the input and the output devices [ICC, 2010].
- Second is preserving the lightness of images spatially for perceptual quality, which consists of image dependent algorithm.

Objectives

Objectives

- To develop a process to enhance the simultaneous lightness contrast of images in spatial domain.
- To evaluate the performance of the process .

Development of method

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Linear Lightness Rescaling

- Linear Lightness Rescaling

Rescaling has been modified by Montag and Fairchild (1997) to remap the lightness of the input data to that of the range of the output destination device the below equation (1.1)

$$L^*_{out} = \frac{L^*_{in} - L^*_{minIn}}{100 - L^*_{minIn}} \left(100 - L^*_{minOut}\right) + L^*_{minOut} \qquad (1.1)$$

The above equation (1.1) scales the *L** values from black point, which maps the lightness values lesser than the L^*_{min} of the image range into the destination range, as a result all the *L** values are scaled linearly in one direction.

More *L** values are pushed to high lightness values which tends the output image to be lighter as well as loss in perceived image contrast [Braun & Fairchild, 1999].

Linear Lightness Rescaling

To overcome the loss in contrast by the linear scaling the below equation (1.2) can be used after processing through the linear equation to recover the contrast which has been lost by linear equation (1.1).

$$L^*_{out} = \frac{L^*_{in} - L^*_{maxIn}}{L^*_{maxIn} - L^*_{minOut}} \left(L^*_{maxOut} - L^*_{minOut} \right) + L^*_{maxOut} \qquad (1.2)$$

The above equation (1.2) maps the L^*_{max} accordingly to the destination L^*_{max} this prevents the perceived contrast lost of the image caused by linear scaling.

Since, the equation takes into account of both the L^*_{minOut} and L^*_{maxOut} of the destination media, i.e black and the white point of the destination media lightness range, it might help us to retain some of the contrast of the image which is lost by the linear lightness scaling.

Example

- An image with mean *L** value equal to 75.73 is processed by the linear equation (1.1) to scale the lightness range within the output range of *L** 15 to 91.5, the average *L** value after processing is 76.75, which is greater than the mean input *L**. This clearly shows that the image tends to become lighter than the source. When the image is processed through the equation (1.2) the average *L** value is 70.55, which shows that image has better perceived image contrast compared with linear lightness scaling.

	L*max	L*min	Mean L*
Input image	100	9.8	75.73
Output media range	91.5	15	-
Linear lightness rescaling - eq 1.1	99.6	14.9	76.75
Linear lightness rescaling - eq 1.2	90.98	14.9	70.55

Table 1.1 *– Comparison of Lightness values between Input and Output*

Spatial Contrast Preserving Algorithm (SCPA)

The image processed through the linear lightness equation (1.1 & 1.2) still has some perceived image contrast loss. In order to regain the lost image contrast and enhance the image, a spatial processing was developed. The spatial processing is developed based on the idea of Bala et al (2000).

The Spatial Contrast Preserving Algorithm which has been developed in this experiment is intended to preserve the perceived image contrast. A block diagram of the proposed algorithm is shown in figure (1.1).

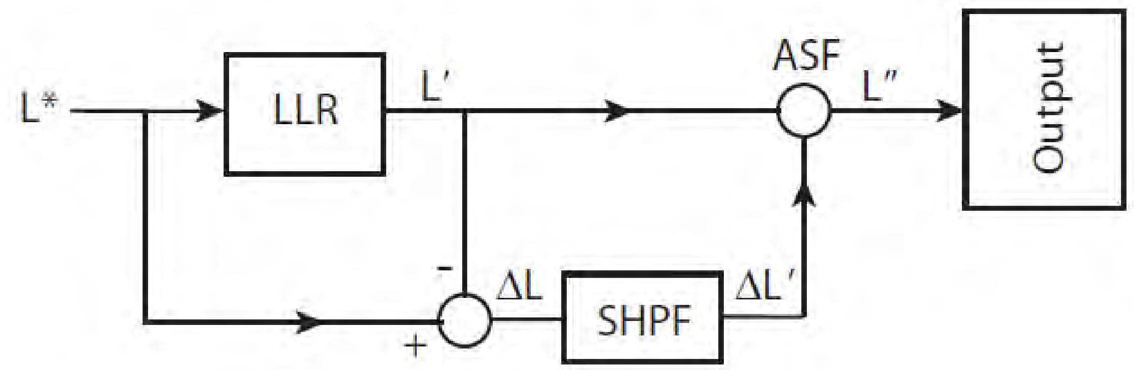

Figure 1.1 *– Block diagram of proposed spatial contrast preserving algorithm*

Spatial Contrast Preserving Algorithm (SCPA)

There are three different stages in the process, they are:

a) Linear Lightness Rescaling (LLR)

b) Spatial High-Pass Filter (SHPF)

c) Adding Spatial Feedback (ASF)

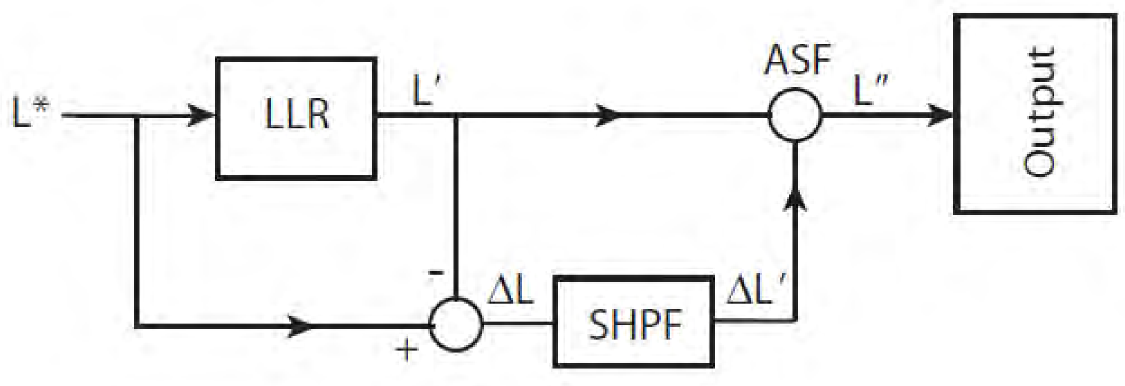

***Figure 1.1** – Block diagram of proposed spatial contrast preserving algorithm*

Spatial Contrast Preserving Algorithm (SCPA)

- *Linear Lightness Rescaling*: The Lightness values of the image are initially processed by using the equation (3.1). *L'* is the output of the lightness values after processed which is within the lightness range of the output media.
- *Spatial High-Pass Filter*: *L'* from the previous process is subtracted from the original *L** values. The difference in *L* values Δ*L* is then taken as the input for the spatial high-pass filter which emphasizes the high frequency details. The output *L** value from the high-pass filter is Δ*L'*.

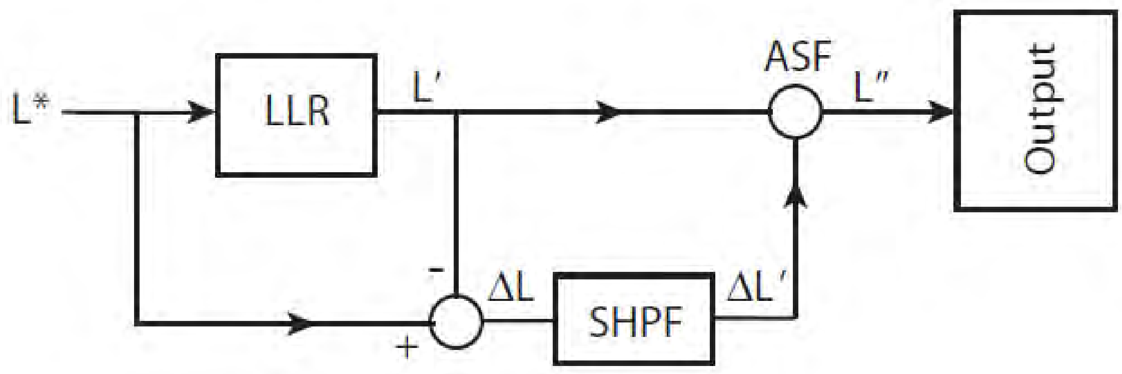

Figure 1.1 *– Block diagram of proposed spatial contrast preserving algorithm*

Spatial High Pass Filter

- The high-pass filter preserves luminance at high spatial frequencies [Bala et al, 2000]. A Gaussian high-pass filter (GHPF) was developed based on the equation (1.3). The transform function with cut off frequency locus at a distance D_0 from the origin.

$$H(u,v) = 1 - e^{\frac{-D^2(u,v)}{2D_0^2}} \qquad (1.3)$$

where *D*(*u,v*) is given by the equation (1.4)

$$D(u,v) = \left[(u - M/2)^2 - (v - N/2)^2\right]^{1/2} \qquad (1.4)$$

D(*u,v*) is the distance from point (u,v) to the centre of the frequency rectangle,
D(*u,v*) is a specified nonnegative quantity.

Spatial High Pass Filter

- The Gaussian filter provides better result when compared with other high-pass filters [Gonzalez & Woods, 2002]. The *Do* value used for this experiment is obtained from the equation (1.5).

$$D_0 = [((r/2) + (c/2))/4] \qquad (1.5)$$

where *r* is the width of the input image and
c is the height of the input image.

Different D0values has been tested and the value has been finalised as the possible value which enhances the contrast of the image without creating any artefacts in the image.

Spatial Contrast Preserving Algorithm (SCPA)

- *Adding Spatial Feedback*: ΔL' from the previous process is added as spatial feedback to the *L'* values obtained from the linear lightness compression process. The combined values are made sure to be within the lightness range of the output media. The final *L"* values combines with *a** and *b** values and form the image.

Note: The *a** and *b** values are same as the source. They are not manipulated. The proposed process is only for the achromatic contrast of the image.

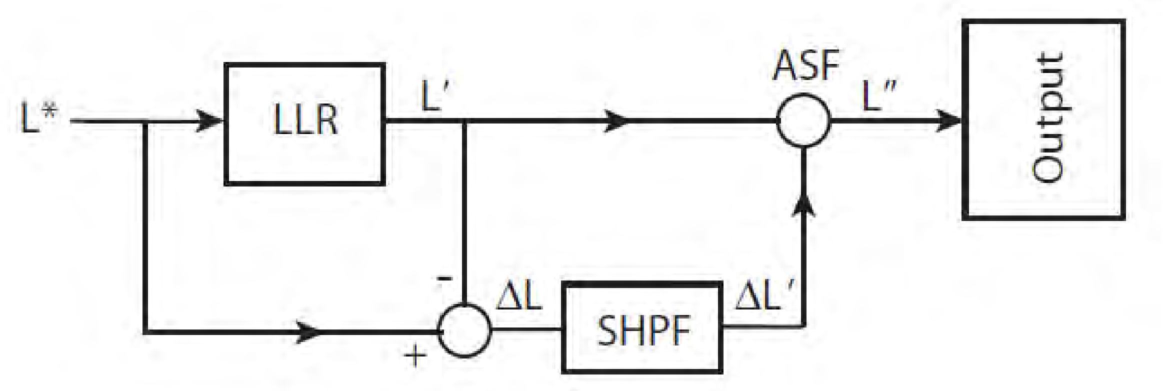

***Figure 1.1** – Block diagram of proposed spatial contrast preserving algorithm*

Design of Experiment

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Selection of images

Kids

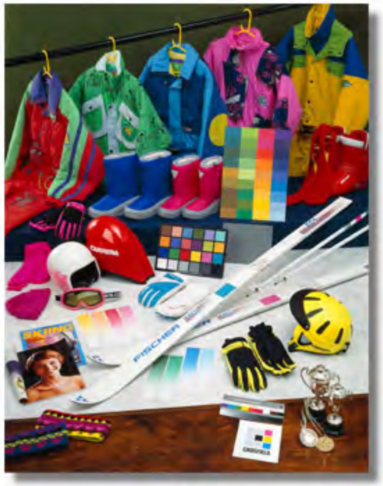
Fruits

Drinks

Flower

Outdoor

Bicycle



Ski

Girls

***Figure 1.2** – Eight test images used in the experiment.*

Selection of images

	Kids	Outdoor	Fruits	Drinks	Bicycle	Flower	Girls	Ski
Mean L*	44.98	49.07	45.14	61.72	75.73	42.61	46.51	46.43
Pixels <15 L*	16.50%	0.50%	0.10%	0.10%	0.10%	0.10%	0.10%	13.80%
Pixels >91.5 L*	1.70%	8.60%	4%	22.50%	38%	6%	7%	7.50%
Out of lightness range pixels	18.20%	9.10%	4.10%	22.60%	38.10%	6.10%	7.10%	21.30%

***Table 1.2** – Sample test image statistics in CIE LAB*

	Kids	Outdoor	Fruits	Drinks	Bicycle	Flower	Girls	Ski
Variance	600.9	614.56	493.6	642.14	598.7	581.58	496.75	827.52
Entropy	7.55	7.37	7.18	7.23	7.41	6.84	7.22	7.68

***Table 1.3** – Sample test image scene statistics*

Selection of images

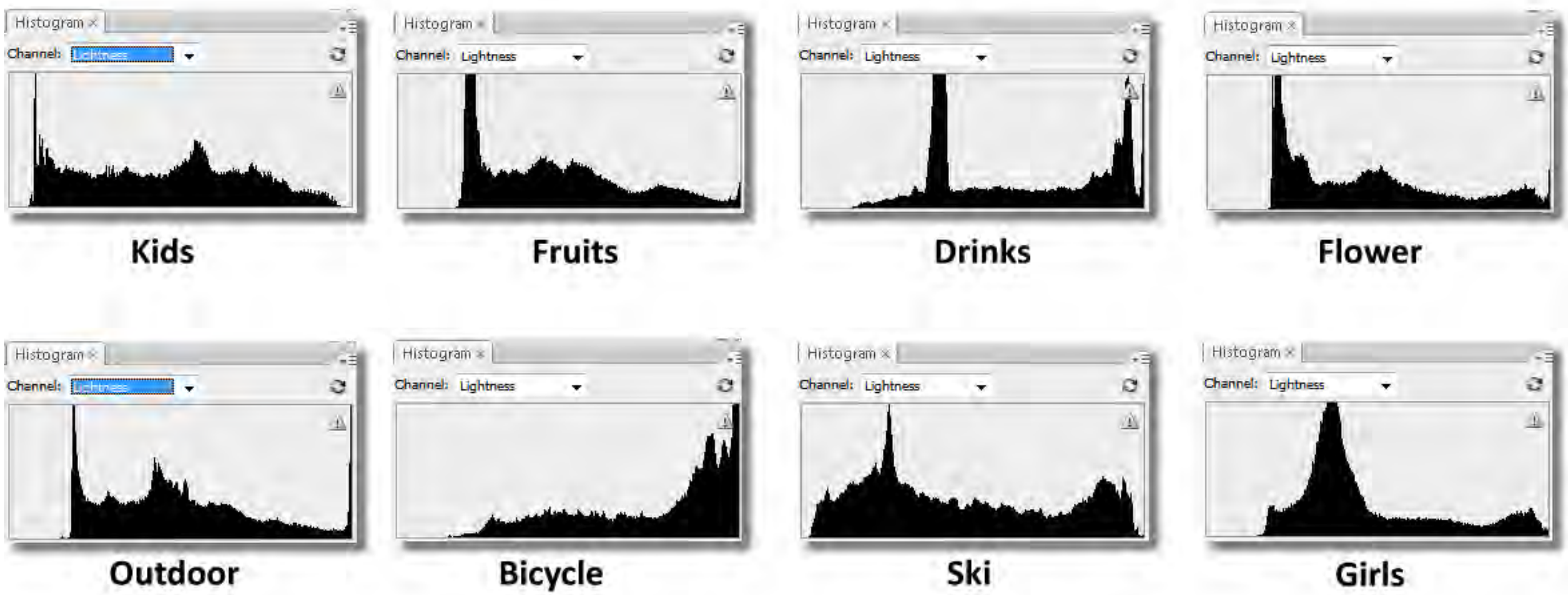


***Figure 1.3** – Lightness histogram of the 8 test images.*

Evaluation

In the evaluation process five algorithms was chosen, they are

- Linear lightness rescaling algorithm
- Sigmoidal contrast enhancing algorithm [*Braun & Fairchild, 1999*]
- Spatial simultaneous lightness contrast enhancement (Proposed)
- Livens contrast enhancement - A [*Livens et al, 2003*]
- Livens contrast enhancement - C [*Livens et al, 2003*]

The observers are asked to rank the sample based on two categories.

- How pleasing the image is?
- Rank the sample based on contrast.

Analysis and Discussion

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Image by Image analysis

Image	Preferred algorithm
Kids	Linear
Fruits	Spatial
Drinks	Spatial
Flower	Linear
Outdoor	Spatial
Bicycle	Linear
Ski	Linear
Girls	Spatial

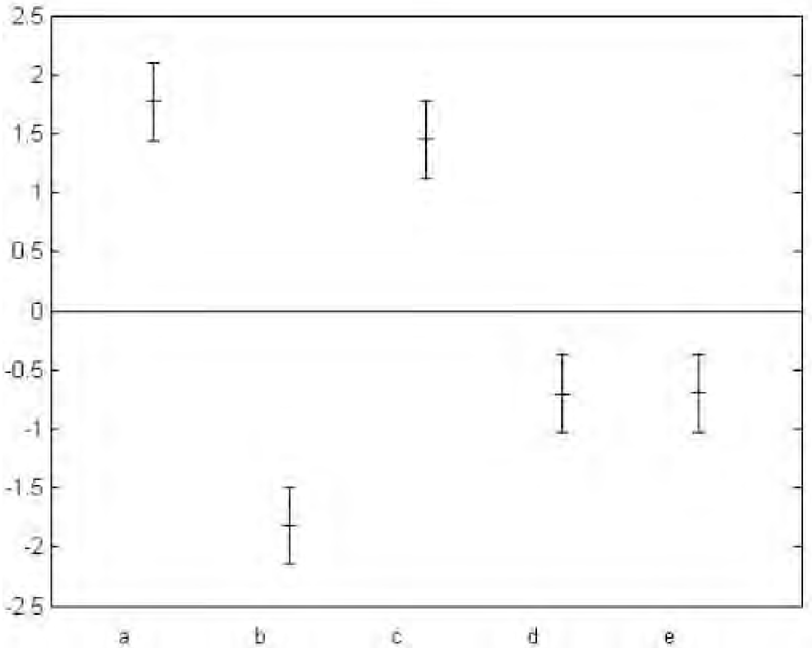
Table 1.4 *– Sample image and the preferred algorithm for pleasantness.*

Image	Preferred algorithm
Kids	Linear
Fruits	Linear
Drinks	Linear
Flower	Linear
Outdoor	Spatial
Bicycle	Linear
Ski	Linear
Girls	Spatial

Table 1.5 *– Sample image and the preferred algorithm for contrast.*

Z-scores where calculated and plotted to visualize the preferred algorithm.

Average Z-scores - Pleasantness

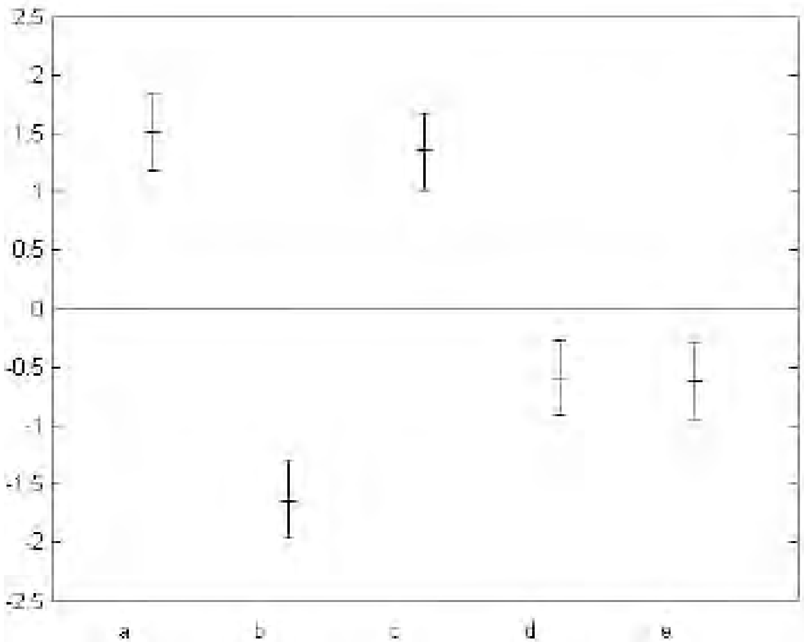


***a** - Linear Lightness rescaling algorithm, **b** - Sigmoidal Contrast enhancing algorithm, **c**-Spatial Simultaneous Lightness Contrast Enhancement, **d**-Livens Contrast Enhancement-A, **e** - Livens Contrast Enhancement - C*

***Figure 1.12** – Average Z-score results for the images based on the judgement of pleasantness.*

The average z-scores of the task which is illustrated in the above figure (1.12), demonstrates that the linear lightness rescaling is preferred widely when compared with other algorithms, when pleasantness is judged for the reproduced images.

Average Z-scores - Contrast



***a** - Linear Lightness rescaling algorithm, **b** - Sigmoidal Contrast enhancing algorithm, **c**-Spatial Simultaneous Lightness Contrast Enhancement, **d**-Livens Contrast Enhancement-A, **e** - Livens Contrast Enhancement - C*

***Figure 1.21** – Average Z-score results for the images based on the judgement of contrast.*

The above figure (1.21) illustrated that the linear lightness rescaling is preferred widely when compared with other algorithms, when contrast is judged for the reproduced images.

Analysis based on Image histogram - Contrast

High Key Image

Linear rescaling algorithm is preferred when compared with other algorithms for the Bicycle image, which is the only falls under the high key image category. It can be visualised from figure (1.17).

Normal Key Images

Kids, Outdoor, Fruits, Drinks, Girls and Ski images falls under the normal key image classification. Most of the images falls within this category. Linear and the Spatial algorithm are mostly preferred which is clearly illustrated from figure (1.13 to 5.16, 1.19, 1.20). Linear is preferred 4 times out of 6 images.

Low Key Image

Low key image classification consists of Flower image. Linear outperforms all the other algorithms, which is clearly illustrated in figure (1.18).

Analysis – Mean lightness

Process\Image	Kids	Outdoor	Fruits	Drinks	Bicycle	Flower	Girls	Ski
Original - Mean L*	44.98	49.07	45.14	61.72	75.73	42.61	46.51	46.43
Linear - Mean L*	52.61	52.16	47.46	63.49	76.75	45.52	49.96	53.82
Sigmoidal- Mean L*	36.24	39.4	34.27	45.23	56.38	32.08	34.77	34.79
Spatial - Mean L*	46.92	48.63	44.65	60.06	72.36	42.44	46.5	48.66
Livens-A - Mean L*	60.4	60.03	64.95	74.68	85.27	58.15	62.09	60.68
Livens-C - Mean L*	66.66	66.08	62.45	74.81	84.2	60.62	64.71	67.23

Table 1.4 *– Comparison of Mean Lightness values of algorithms used in the experiment.*

Table (1.4) illustrates the mean lightness values of the original image and the output image from five different algorithms used in this experiment. The Linear and Livens - A & B increases the mean lightness value, while Spatial decreases the mean lightness values remarkably. The Spatial algorithms maintains the mean lightness values nearer to the original mean values.

Impact of other factors in evaluation

- In this experiment the lightness contrast has been processed by the algorithm, the colour contrast has not been managed. But, when evaluating the algorithms, the lightness contrast alone cannot be evaluated, also there could be an effect of the colour contrast while judging the reproduction by the observers.
- The level of illuminance under which the reproduction are judged has also have a effect on the judgement. The previous experiment which was carried out at different level of lux shows that there is a considerable difference in judgement while evaluating the reproductions [Vaitiyanathan, 2010]
- While judging the samples there is possibility of Stevens effect, which indicates that as the luminance level increases, dark colours appears darker and the light colours tends to appear lighter as summarised by Fairchild M (2005).

Conclusion

Conclusion

- A simultaneous lightness contrast enhancing algorithms has been proposed that takes into account the spatial characteristics of the image. The algorithm is designed in a way that it can be automated to map the lightness range of the image based on the output media lightness range. The algorithm doesn't produce any noise or artefacts.
- The spatial algorithm is aided by linear lightness scaling from both black and white point of the lightness range. It also assists in contrast enhancement.
- Psychophysics experiments indicate that the spatial algorithm reproduces images which have normal lightness. Also, it best suits for images which consist of live scene and skin tones.
- Linear lightness rescaling have performed consistently better than all the other algorithms across images.
- The image statistics analysis shows that the spatial algorithm reproduces mean lightness nearer to that of the original

Conclusion

- Since, contrast enhancement is subjective based on the observer judgment, the proposed spatial algorithm can be used for mapping the lightness range, which can then be accomplished with other contrast enhancement algorithms based on the observer requirement.
- The algorithm can also be further modified to enhance the perceived image lightness contrast by decreasing the *D*o value in the equation (3.3) subjective to observer.
- Considering different image characteristics the spatial algorithm can be further extended to make it image adaptive.

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Thanks for your time

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