Fadeless Image Projection Preserving Local Contrast Under Ambient Light

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Abstract

This paper presents a simple but novel solution to enhance the image contrast on the screen projected with ambient light. The proposed algorithm is designed to preserve a local image contrast based on a luminance ratio of a pixel to its local surround in attention. The projected image loses its visual contrast and color when viewed in ambient light using auxiliary lamp in place of room light, because each pixel RGB value is biased by the additional surround illuminant. First, the proposed algorithm transforms an original image to a projected image on the screen in the dark room. Next, since the dynamic range of the projected image under ambient light is narrowed as compared with the original, the gamma compression is assumed to map the original input range into the displayed output range. Thirdly, the local contrast of the displayed image lowered by ambient light is enhanced to match with that of the original. Finally, the biased luminance level is compensated by linear correction for output RGB signal to shift the ambient luminance offset level into zero level. As a result, the visual impression of the projected image or the motion picture with ambient light is kept as much the same contrast as seen in the dark room.

Introduction

HDR (High Dynamic Range) imaging is an exciting topic and becoming more popular. Although most of existing display devices have LDR (Low Dynamic Range), there is a very strong demand for displaying the wide range of natural scenes by mapping HDR to LDR as realistic as possible. A lot of work has been done on this topic,[1] which are roughly classified into spatially invariant[2-5] and spatially variant[6-9] tone-mapping. Now the latter is stepping into spatial vision models.[10,11] These approaches are mostly addressed to make the visual appearance matching by the dynamic range compression from HDR to LDR.

Our proposal has a different objective from the above, which is addressed to enhance the visual contrast for the conventional LDR image on the screen projected under ambient light. The paper discusses the algorithm for mapping LDR to LDR to recover the visual contrast under ambient light and introduces the experimental results supported by psycho-physical evaluation.

Though the brightness of LCD or DLP projectors has been considerably improved in recent years, a high-quality projection image with high-contrast is still requested to be viewed in the dark room without ambient light. It would be helpful if these images could be displayed with the high visual contrast under ambient light with enough luminance to read the documents at a meeting or a conference.

Local Contrast Preserving Image Projection System

According to Tumblin's LCIS based approach,[12] a scene luminance is separated into two components, the "profile" and the "detail". The profile carries smoothly changing low frequency basis and the detail reflects high frequency components. A whole image is produced by overlaying the detail on the profile.

Figure 1 illustrates an overview of a proposed system. The objective of the system is to control the luminance on the screen with ambient light. First, an original image is transformed to the projected image on the screen in the dark room by linearly scaling *RGB* components to shift zero level into the minimum luminance level. The local contrast of this image is treated as the target contrast. Next, the projected *RGB* image is transformed into the luminance ***Y*** component, and the separated chroma (***C***) components are reserved and used for local contrast range transform process later. Here, a spatial filter is convolved to the ***Y*** component to take a local average (***LA***) surrounding the pixel in attention. Taking the ratio of the ***Y*** component to ***LA***, we get a local contrast gain (***CG***) corresponding to the image detail. Thirdly, the luminance ***Y*** component is modulated by ***CG*** to keep the local contrast as same as the original viewed in the dark room. Finally, the modified luminance ***Y'*** component is combined with the chroma ***C*** components and inversely transformed into the corrected *R'G'B'* image. In the post process to project the corrected image on the screen, the offset components caused by ambient light is reduced from *R'G'B'* by linear scaling function to shift the ambient luminance offset level into zero level.

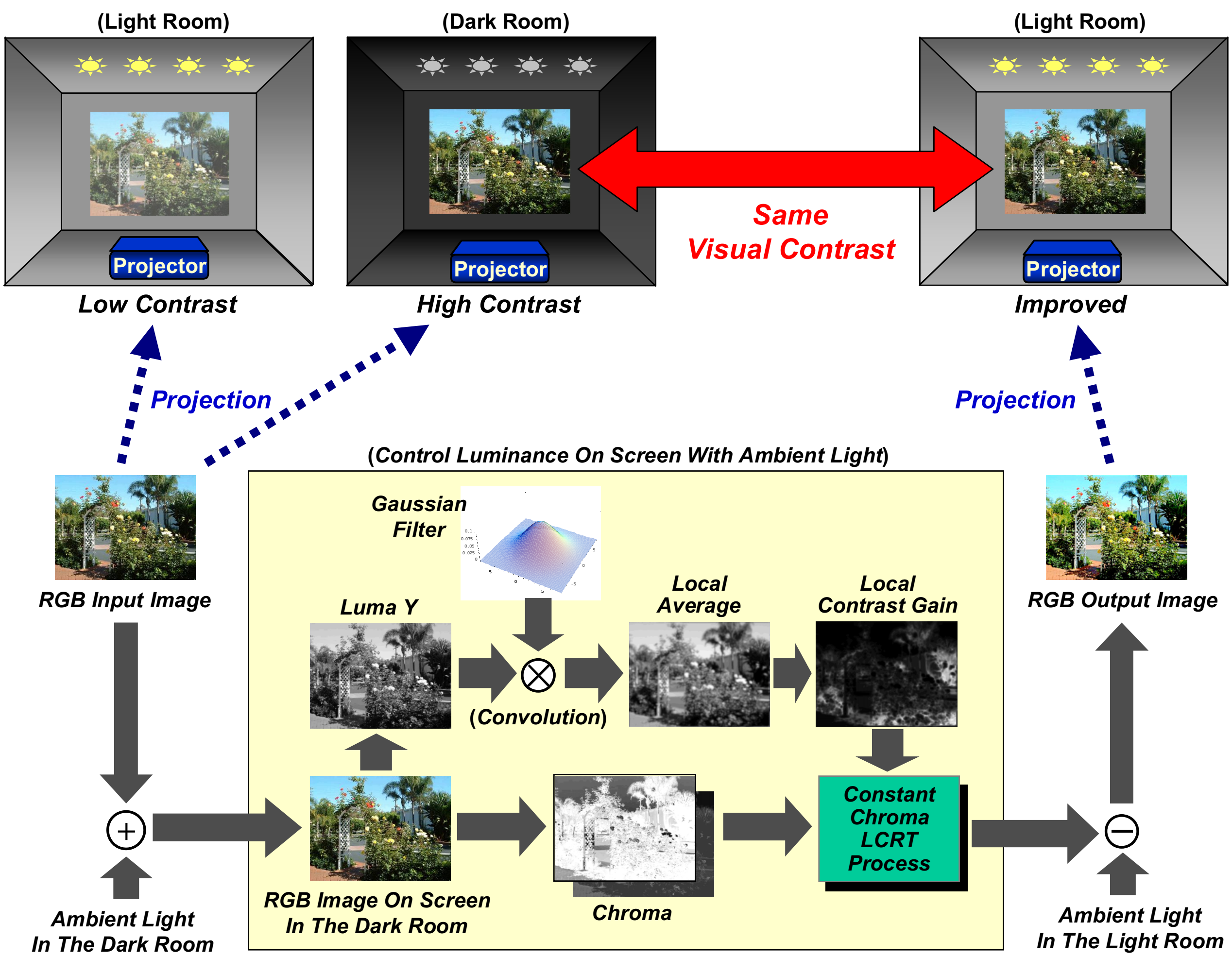


Figure 1. Overview of Local Contrast Preserving Image Projection System

Local Contrast Range Transform

We introduce a popular gamma compression function for mapping the input range to the output range. Denoting the local average of the input image $f(x,y)$ as $f_{ave}(x,y)$ and the local average of the output image $g(x,y)$ as $g_{ave}(x,y)$, the output local average $g_{ave}(x,y)$ after gamma compression is approximately given by

$$g_{ave}(x,y) = f_{ave}(x,y)^{\gamma} \tag{1}$$

First of all, we should notice a minimum luminance level $f_{min}(x,y) = f_{dark}$ in the dark room is mapped to the minimum luminance level $g_{min}(x,y) = g_{light}$ on the screen with ambient light. Thus we decide the gamma value corresponding to the ambient illuminant level g_{light} as

$$g_{light} = f_{dark}{}^{\gamma} \qquad \gamma = \frac{\log(g_{light})}{\log(f_{dark})} \tag{2}$$

A mathematical condition to keep the local contrast after vs. before processing is simply described as

$$\frac{g(x,y)}{g_{ave}(x,y)} = \frac{f(x,y)}{f_{ave}(x,y)} \tag{3}$$

Replacing the output local average $g_{ave}(x,y)$ by equation (1)

$$g(x,y) = \left\{\frac{g_{ave}(x,y)}{f_{ave}(x,y)}\right\} \times f(x,y) = f(x,y)^{\gamma} \times \left\{\frac{f(x,y)}{f_{ave}(x,y)}\right\}^{1-\gamma} \tag{4}$$

This equation is a basic formula of our ***LCRT*** (*Local Contrast Range Transform*) process.

Figure 2 shows the input-to-output mappings of ***LCRT*** in case of f_{dark} = 0.01 and g_{light} = 0.1 which lead γ = 0.5. The curving line in Figure 2 shows the relation of gamma compression for mapping the input range to the output range. When the input luminance $f(x,y)$ is equal to the local average $f_{ave}(x,y)$, the output luminance $g(x,y)$ is found on this curve as shown by dots which are located on the mapping points corresponding to $f(x,y)$=0.2, 0.4, 0.6 and 0.8, respectively. When the input luminance $f(x,y)$ is not equal to the local average $f_{ave}(x,y)$, the input luminance $f(x,y)$ is transformed along the straight line decided by the local average $f_{ave}(x,y)$ as shown by the thin dashed lines for preserving the local contrast. The thick line segments show the output luminance computed from the input luminance between $f_{ave}(x,y)$-0.1 to $f_{ave}(x,y)$+0.1 for each $f_{ave}(x,y)$.

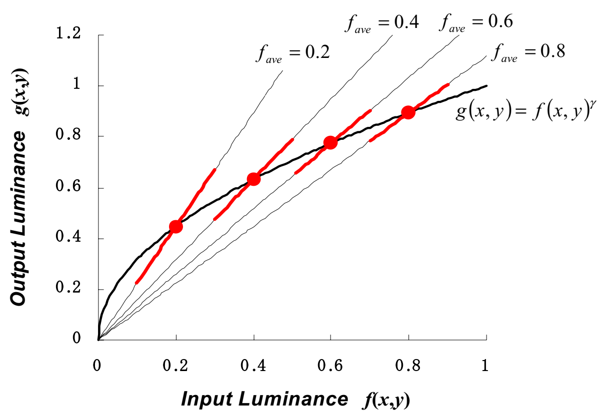


*Figure 2. Input-to-Output Mappings of **LCRT***

Here, the local average $f_{ave}(x,y)$ is calculated by taking a convolution of the spatial averaging filter $G(x,y)$ and the input image $f(x,y)$ as follows.

$$f_{ave}(x,y) = \langle G(x,y) \otimes f(x,y) \rangle \tag{5}$$

In our basic model, Gaussian function is introduced as a spatial filter given by

$$G(x,y) = K\exp\left\{ \frac{-(x^2+y^2)}{\sigma^2} \right\} \tag{6}$$

$$\iint G(x,y)dxdy = 1 \tag{7}$$

where σ denotes a standard deviation which determines a kernel size M. In practice, the kernel size M=4σ+1 should be sufficient for integer value of σ taking ±2σ spread into consideration.

These processes are basically applied to the luminance channel which carries most of visual spatial information. In this paper, we examined our algorithm for the following three different sets of *Luma-Chroma* combinations.

Luma-Chroma Channel Process

LCRT drastically changes the luminance value for each pixel to preserve the visual contrast in the light room. Here, the impression of chrominance should be also preserved as same as the original seen in the dark room. To find out the *Luma-Chroma* process suitable for this algorithm, we tested the following three different sets.

[1] RGB Separate Channel Process by Y in YIQ Space

This process firstly transforms a *RGB* image to the *Y* component in *YIQ* space. Next, ***CG*** is calculated taking a ratio of *Y* to ***LA***. Finally, multiplying *RGB* components signal by ***CG***, the modified image is generated.

In this process, the ratio of *RGB* components is not changed so that the chromaticity is preserved. In short, we call this process ***RGB-Proc***.

[2] YIQ Luma-Chroma Process by Luminance Y

This process firstly transforms a *RGB* image to the *YIQ* image. Next, the modified *Y'* component is calculated by applying ***LCRT*** to the *Y* component. Then the modified *Y'* component is combined with the chroma *IQ* components and inversely transformed into the corrected *R'G'B'* image.

In this process, only the luminance *Y* component is changed and the chroma *IQ* components are preserved. In short, we call this process ***YIQ-Proc***.

[3] LAB Lightness-Chroma Process by Y in XYZ Space

This process firstly transforms a *RGB* image to the *XYZ* image. Next, *a** and *b** components in CIELAB space are calculated from the *XYZ* image and preserved. Then, ***LCRT*** is applied to *Y* component. Then the modified *Y'* component is transformed into *L*'* component and combined with preserved *a** and *b** components. Finally, *L*'a*b** components are inversely transformed into the corrected *R'G'B'* image via the *X'Y'Z'* image.

In this process, only the lightness *L** component is changed through the modified luminance *Y'* component and the chromatic components *a** and *b** are preserved. In short, we call this process ***LAB-Proc***.

Experimental Results

We experimented the proposed algorithm for several test images with 720×480 pixels. Figure 3 shows the resultant images for the above three different sets of *Luma-Chroma* process (***RGB-Proc***, ***YIQ-Proc*** and ***LAB-Proc***). In this experiment, a minimum luminance level f_{dark} in the dark room and g_{light} in the light room are set to 0.01 and 0.1, respectively. A standard deviation of Gaussian operator was set to σ=32 and a kernel size of a Gaussian filter to M=129.

Considering the visual contrast of the resultant images, we should take notice that the original images and the resultant images have to be seen in different viewing conditions because ***LCRT*** process enhances the visual contrast lowered by ambient light to match to that of the original seen in the dark room. Thus, when they are seen at the same time as shown in Figure 3, the contrast of the resultant images looks over-enhanced as compared with that of the original. But their visual contrast is almost the same as seen in the corresponding viewing environment.

As for the color appearance, they look to be clearly different one another for the three types of *Luma-Chroma* channel processes. When they are seen in the corresponding viewing condition, the resultant images by ***RGB-Proc*** look over-enhanced with higher color saturation and the resultant images by ***YIQ-Proc*** look severely de-saturated. On the contrary, the resultant images by ***LAB-Proc*** give the visual impression almost same or slightly de-saturated as compared to the original image without ambient light. These results show that ***LAB-Proc*** brought the closest visual impression to the original in the dark room.

Psycho-Physical Evaluation

A psycho-physical evaluation has been performed to test the validity of ***LCRT*** process. More specifically, this test examines whether the visual impression of the resultant image by ***LCRT*** with ambient light is kept as much the same as the original seen in the dark room. Here, a pair comparison experiment based on Thurstone's law was introduced as illustrated in Figure 4.

In this experiment, two LCD projectors are used; ***Projector1*** for the projection of the test images and ***Projector2*** for the overlay of uniform white light as a substitute for ambient illuminant, respectively. First, ***Projector1*** projects two original images side by side and ***Projector2*** projects dark uniform light ($f_{dark} \cong 0.01$) to make a condition of the dynamic range of 1:100. This screen image is seen by an experimenter about 10 seconds to memory the impression of its visual contrast. Next, the projected images by the two projectors are simultaneously changed: ***Projector1*** projects two sample images processed by ***LCRT*** with different parameters and ***Projector2*** overlays uniform light ($g_{light} \cong 0.05$) to make a condition of the dynamic range of 1:20. Again, this screen image is seen by an experimenter about 10 seconds to judge whose sample image's visual contrast is preserved nearer to the original image without ambient room light. This examination is repeated for all combinations of the sample images processed by ***LCRT*** with different parameters.

(a) Original Images *(b) Results of **RGB-Proc*** *(c) Results of **YIQ-Proc*** *(d) Results of **LAB-Proc***

*Figure 3. Experimental Results by **LCRT** for Three Different Sets of Luma-Chroma Process*

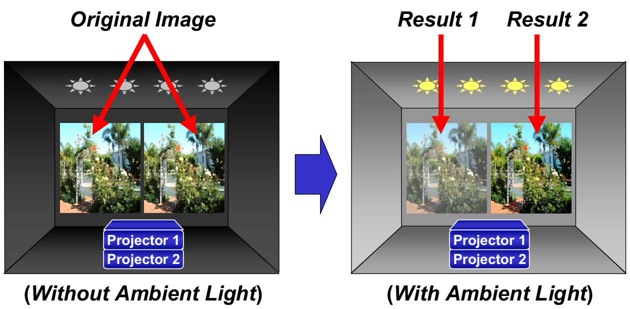


Figure 4. Psycho-physical Evaluation by Pair Comparison

In this experiment, two kinds of test images ("Cognac and Fruit" and "Streetcar") are evaluated. They are processed by ***LCRT*** for $f_{dark} \cong 0.01$ and $g_{light} \cong (0.01, 0.025, 0.05, 0.067, 0.1)$. According to the conclusion in previous section, ***LAB-Proc*** is applied to all the test images. These processed images are shown in Figure 5. Here, five resultant images are generated for each test image so that the number of pair comparison is counted as 10. The image size is 720×480, and a standard deviation σ of the Gaussian function and a kernel size M is set to 32 and 129, respectively.

The sample images were evaluated by 17 experimenters. The results are analyzed using Thurstone's Law of comparative judgment and z-scores are calculated. The results are illustrated in Figure 6.

In this experimental condition, the results of "Cognac and Fruit" and total of two images demonstrate the validity of proposed ***LCRT*** algorithm, because experimenters judged that the visual impression of the image processed using a parameter just corresponding to the dynamic range of the real viewing condition ($g_{light} \cong 0.05$) is kept nearest to original seen in the dark room. On the other hand, as for the result of "Streetcar", it shows that the image processed using $g_{light} \cong 0.025$ is judged closer to the visual contrast of the original than that of $g_{light} \cong 0.05$. The reason of mismatch is considered interviewing to experimenters as follows: since the image "Streetcar" is taken as a cloudy scene, a little vague image might be judged suitable for its situation.

In summary, the result of psycho-physical evaluation demonstrates that ***LCRT*** algorithm with ***LAB-Proc*** is a useful transform to preserve the visual contrast when ambient light is changed.

Discussion and Conclusion

The paper proposed a novel image contrast enhance algorithm. The proposed algorithm claims the advantages to improve the visual contrast on the screen for projection images under the light surround.

(a) g_{light} = 0.01 (original)

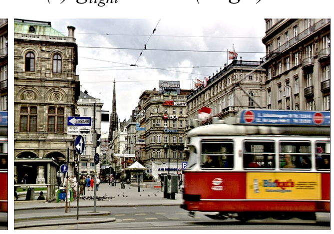

(b) g_{light} = 0.025 *(c) g_{light} = 0.05 (target)*


(d) g_{light} = 0.067 *(e) g_{light} = 0.1*

"Cognac and Fruit"

(a) g_{light} = 0.01 (original)


(b) g_{light} = 0.025 *(c) g_{light} = 0.05 (target)*

(d) g_{light} = 0.067 *(e) g_{light} = 0.1*

"Streetcar"

Figure 5. Sample Images for Psycho-Physical Evaluation

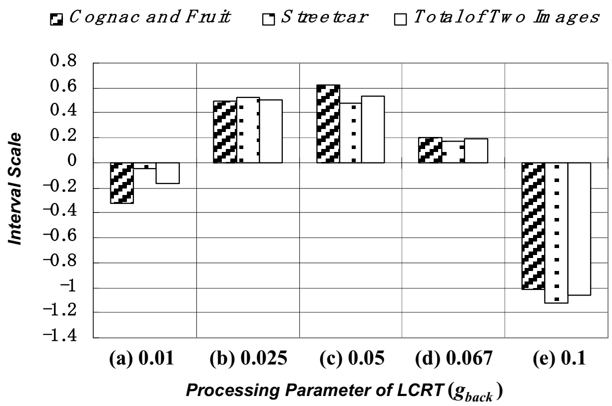


Figure 6.Interval Scale Results in Psycho-Physical Evaluation

The paper states the following conclusion.

- *LDR of the input image narrowed by the surround illumination is simply mapped to the LDR of projection image by a single gamma parameter reflecting the ambient luminance level.*
- ***LCRT** algorithm automatically enhances the visual contrast lowered by the ambient light in the light room to match to that of the original in the dark room by preserving the spatial local contrast.*
- *Performance of **LCRT** algorithm was experimentally demonstrated through psycho-physical assessment.*
- *Among the Luma-Chroma combinations, **RGB-Proc**, **YIQ-Proc** and **LAB-Proc**, **LAB-Proc** brought the closest visual impression to the original.*

In this paper, a popular gamma compression function is employed for the dynamic range compression. But it is not absolutely the best selection for this purpose. We are going to examine another candidate such as sigmoid function in our future work. In addition, since the proposed algorithm currently costs a lot of processing time, the implementation for faster processing is also left to our future work in order to come into practical use.

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Biography

Yusuke Monobe received his B.S. and M.S. degrees in electrical engineering from Kyoto University, Japan, in 1996 and 1998, respectively. In 1998, he joined Matsushita Electric Industrial Co., Ltd. He has been working in digital color image processing. He is currently pursuing his Ph. D. degree as an adult student in Doctorate Program in the Graduate School of Science and Technology, Chiba University, Japan. His research interests include color imaging, and computer vision. He is a member of the Institute of Electronics, Information, and Communication Engineers of Japan.