

A Comparative Study of Various Tone Mapping Methods

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Abstract—In the recent years, high dynamic range imaging has gain popularity with the advancement in digital photography. In this contribution we present a subjective evaluation of various tone production and tone mapping techniques by a number of participants. Firstly, standard HDR images were used and the participants were asked to rate them based on a given rating scheme. After that, the participant was asked to rate HDR image generated using linear and nonlinear combination approach of multiple exposure images. The experimental results showed that linearly generated HDR images have better visualization than the nonlinear combined ones. In addition, Reinhard et al. and the exponential tone mapping operators have shown better results compared to logarithmic and the Garrett et al. tone mapping operators.

Keywords—tone mapping, high dynamic range, low dynamic range, bits per pixel.

I. INTRODUCTION

REALworld scenes have various intensity ranges which expand from dim starlight to direct sunlight. However, existing cameras can only capture a limited range of intensities [1]. Common cameras and display devices are capable of displaying 24-bit depth per pixel (8 bits per channel) which cannot cover the actual luminance of the scene which is called low dynamic range. Dynamic range is defined as the ratio of maximum to minimum intensity that can be represented by the system [2]. In the recent years, the demand for HDR images have been driven by the need to capture real world images which contains various illumination ranges. In addition, the perforation of computation power of computers helps in overcoming the computational burden of HDR image generation/reproduction.

High dynamic range images are generated using special cameras that capture multiple low dynamic range (LDR) images with different exposures times. Then these images are combined together in order to get an image with high dynamic range. There are different techniques for combining multiple exposure images which could be classified into two classes; global and local methods. The global methods compute a global normalization factor that penalizes the whole image without considering its spatial information [3]. The local methods consider local adaptation of image data by grouping smaller rectangular windows together and processing them in similar manner to the global approach. Our human visual

system (HVS) uses local control sensitivity in the retina in order to captures high dynamic range images.

HDR images are used in various applications which require capturing the global illumination which contain wide range of brightness and cannot be captured with naked eye or by cameras. HDR imaging techniques are used in computer graphics and image processing.

In this paper, we present a method for assessing various HDR image techniques. The remaining of this paper is organized as follows. Section II presents some of the published work on HDR imaging which includes generation, visualization as well as evaluation. Section III discusses about HDR production techniques. Section IV discusses some of the well-known tone mapping operators. Section V discusses about evaluation of HDR images. Finally, section VI provides a brief conclusion about this work and restates the main findings.

II. RELATED WORKS

High dynamic range imaging has the subject of research for many years and various methods have been proposed for generating HDR images as well as visualizing these images. In this section, we scan through some of the earlier works on HDR images with emphasis on algorithms proposed for evaluating HDR imaging techniques.

A. HDR Image Generation

Jinno et al. [4] created HDR image by combining multiple exposure images. They employed block matching method for motion compensation. Jo and Vavilin [5] used a variable exposure time in order to increase the dynamic range of images. Lim et al. [6] generated multiple images with different exposure time from one image by using intensity mapping function instead of camera response curve. The mapping function was obtained using two images with known exposure time. Vavilin et al. [3] generated HDR image by combining under-exposed image with over-exposed one for each pixel in the image. Vavilin and Jo [7] adopted a recursive HDR generation image by decomposing regions with high dynamic range into smaller rectangles with small dynamic range then computed the best exposure for each region. Then a Gaussian filter is used to smooth the inter-regional transition.






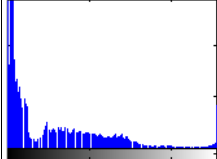
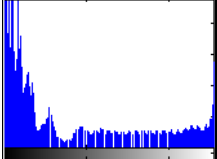
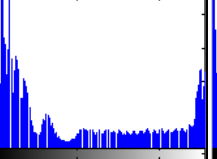
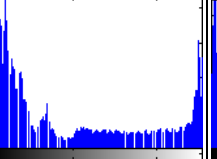
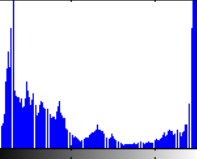
B. Tone Mapping

Tone mapping methods compress the brightness range of the image while maintaining the contrast. Dargo et al. [8] proposed logarithmic compression of luminance values by adaptively varying the logarithmic bases. They used contrast enhancement to improve the contrast of dark areas in image.

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TABLE I
LDR IMAGES WITH DIFFERENT EXPOSURE TIME

| Image |  |  |  |  |  |
|---------------|---|---|---|--|---|
| L-histogram |  |  |  |  |  |
| Exposure time | 0.1ms | 0.4ms | 1.0ms | 4.0ms | 20.0ms |

Duan et al. [2] used histogram adjustment technique to enhance the visualization of the image obtained using global tone mapping operators. They segmented the image into smaller segment then they adjusted adaptively the contrast of each segment using a global histogram operator. Guangjun and Yan [9] used a logarithmic normal distribution for tone mapping instead of normal distribution. Li et al. [10] decomposed the HDR image into base layer which contains the overall luminance of the image and detailed local luminance layer. They used a statistical-based histogram adjustment to map the base layer into low dynamic range while the detailed layer is mapped using a spatial filtering approach.

C. HDR Image Evaluation

Park and Montag [11] evaluated nine tone mapping methods using psychological experiment measures which are the preference and the scientific usefulness. The preference is a measure to the observer's preference among a given choices. Cadik et al. [12] defined a perceptual attributes for evaluating HDR images. These measures include the brightness, color reproduction, contrast, details reproduction and presence of artifacts.

III. HDR IMAGE GENERATION TECHNIQUES

Common digital cameras can only capture a limited range of luminance due to sensor's characteristics which cannot capture the full luminance range of the scene. Therefore, all the details of the scene will not be present in the captured image [13]. In general, a HDR image is created by combining multiple Low Dynamic Range (LDR) image captured at different exposure time. At shorter exposure time, only the high luminance areas of the image are captured as it is shown in figure 1 where the outdoor area has very high luminance because it is subjected to direct sun light. Thus a clear image can be captured even at very short exposure time. On the other hand at longer exposure time, sensors at the indoor regions have sufficient time to capture sufficient amount of light while the sensors at the outdoor regions are saturated and it appears very bright.

A. Linear Combination of LDR Images

This method assumes that the camera has a linear response curve after omitting the saturated and under-exposed pixels.

Thus each pixel will be properly exposed in one or more images and the HDR image can be generated by taking a weighted average of the properly exposed images for each pixel. In reality cameras are not perfect light sensors and motion blur is very prominent between these images because neither object nor camera kept still while capturing these images. Thus this technique requires motion compensation (pixels alignment) as well as ghost and lens flare removal [1].

B. Nonlinear Combination of LDR Images

This method addresses the nonlinear nature of mapping multiple images with different exposure time into single HDR image. Firstly, this method constructs the camera response curve by exploiting the physical properties of the imaging system. The computation of the response curve is formalized as a least square minimization of an ill-posed problem and detail steps for computing the response curve are illustrated in [14]. This response curve is used to convert pixel values into relative radiance maps assuming a known exposure time. The number of photographs needed to recover the full dynamic range of the scene should be rationale to the dynamic range covered by the camera.

IV. TONE MAPPING METHODS

Displaying devices has limited dynamic range; most display devices support 24-bit per color pixel. HDR images are reproduced into a lower dynamic range in order to be displayed in normal display devices. Tone mapping is the process of reducing the dynamic range of the HDR image in order to be displayed on an LDR displaying device while maintaining the image integrity. Tone mapping operators are classified into four classes; global, local, frequency domain and gradient domain operator.

The classification is done to differentiate operators roughly based on how light reflects from a diffuse surface from operators working directly on the pixels. A global operator uses the entire image as the neighborhood for each pixel. Therefore, same compression curve is used to compress each pixel. Local operators use the pixel's neighborhood to compute the pixel's adaptation level and different compression curve is used for each pixel [1]. Frequency operators reduce the dynamic range based on the spatial frequency of a selected

part in the image while gradient operators use the gradient component for reducing the dynamic range. Here is a list of well-known tone mapping methods used in this study:

1) Logarithmic

It uses a logarithmic function to compress the luminance component of the HDR image. Then gamma correction algorithm is used to compress each channel in the RGB image [1].

2) Modified logarithmic

It adopts a separate luminance function for each image channel. The luminance is computed for each channel of the RGB image then the same luminance gain is used for compressing the said channel of the RGB image [1].

3) Exponential

An exponential function is used for mapping the luminance instead of the logarithmic function [1].

4) Modified exponential

Similar to the modified logarithmic method, a separated luminance mapping is generated for each channel of the RGB image [1].

5) Reinhard et al. global operator

It is a modified version of the exponential operator where the luminance is compressed in a controllable fashion using a low luminance key and high luminance key [15].

6) Reinhard et al. local operator

This is similar to the pervious operator. The only different is that a special blurring function is applied on the HDR image before tone-mapping [15].

7) Garrett et al.

They used image appearance model to develop a tone-map curve that consider the surrounding of the pixel [16].

V. EVALUATION OF HDR IMAGES

In this work, different HDR image generation and tone mapping techniques have been implemented. Firstly, different images were captured at different exposure time. Then two HDR generation algorithms were used for generating HDR images. After that tone mapping algorithms are used to convert the image back to LDR format so it can be displayed in normal display devices. Finally, the obtained image has been evaluated subjectively and objectively. Table 2 lists the implemented HDR generation and tone mapping algorithms.

TABLE II
IMPLEMENTED COMBINATION OF HDR GENERATION AND TONE MAPPING METHODS

| Acronym | Tone mapping algorithm | HDR generation method | |
|---------|---|-----------------------|-----------|
| | | Linear | Nonlinear |
| LTM | Logarithmic | √ | √ |
| MLTM | Modified logarithmic | √ | √ |
| ETM | Exponential | √ | √ |
| METM | Modified exponential | √ | √ |
| RGTM | Reinhard et al. method with global operator | √ | √ |
| RLTM | Reinhard et al. method with local | √ | √ |

| | operator | | |
|-----|-----------------------|---|---|
| GTM | Garrett et al. method | √ | √ |

The implemented methods in TABLE II have been implemented firstly on standard HDR images in order to evaluate the performance of the tone mapping methods. After that, HDR images have been created using the linear and nonlinear LDR combination methods. These produced images have been rated subjectively by twelve users. The viewer's rate the image based on TABLE III which shows five different scales for each image.

TABLE III
RATING SCALE USED IN OBSERVER EVALUATION

| Value | Rating | Description |
|-------|-----------|--|
| 6 | Excellent | Extremely high quality, as good as you could desire. |
| 5 | Fine | High quality, providing enjoyable viewing. |
| 4 | Passable | An image of acceptable quality. |
| 3 | Marginal | Poor quality image; you wish you could improve it. |
| 2 | Inferior | A poor image, but you could watch it. |
| 1 | Unusable | An image so bad that you could not watch it. |

A. Tone Mapping for Standard HDR Images

Figure 1 shows the rating of selected tone mapping method on four standard HDR images. A result for one of these images is shown in the figure 4. RGTM and RLTM methods achieved the best rating by preserving the scene details. Similarly, ETM shows good visualization with fewer loses in image details. Other techniques have poor results; the logarithmic tone mapping (LTM and MLTM) has very dark results. GTM produced a grayish image while the METM lost details in bright areas.

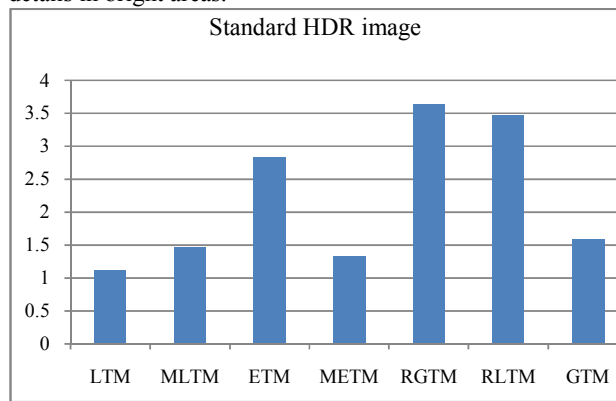


Fig. 1 Rating obtained for tone mapping for standard HDR images

B. Tone Mapping on Images Generating Using Linear HDR Generation methods

For this experiment, four HDR images were generated from a series of differently exposed images using the linear combination method. Then the selected tone mapping algorithms have been applied on the generated HDR images. Similar the standard HDR images, Reinhard et al. methods (RGTM and RLTM) achieved the highest rating followed by the modified exponential method. Garrett et al. has higher rating than the previous set. In MLTM and METM, both

achieved low rating because the image is very purplish.

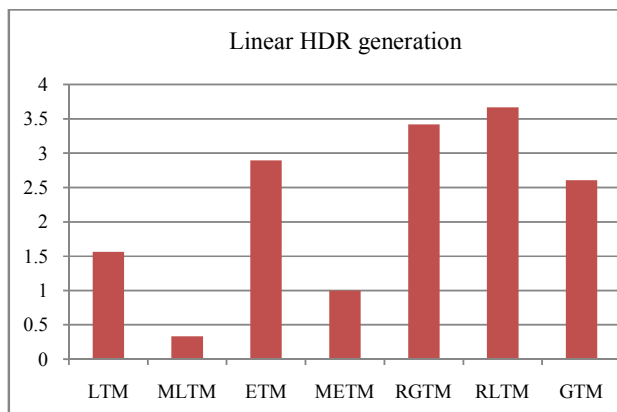


Fig. 1 Rating obtained for tone mapping for HDR images generated using linear method

C. Tone Mapping on Images Generated Using Nonlinear HDR Generation Methods

Four HDR images were generated for this experiment using the nonlinear combination method proposed in [14]. Then the selected tone mapping algorithms were applied on these HDR images. Fig. 3 shows the rating obtained for these images by twelve observers. Reinhard et al. methods and the modified exponential tone mapping techniques achieved the highest scores. Although the score is generally lower than the one achieved for the previous sets of images because the image is very greenish. LTM method achieved higher score compared to the previous sets. MLTM, METM and GTM show very poor quality and they have low rating.

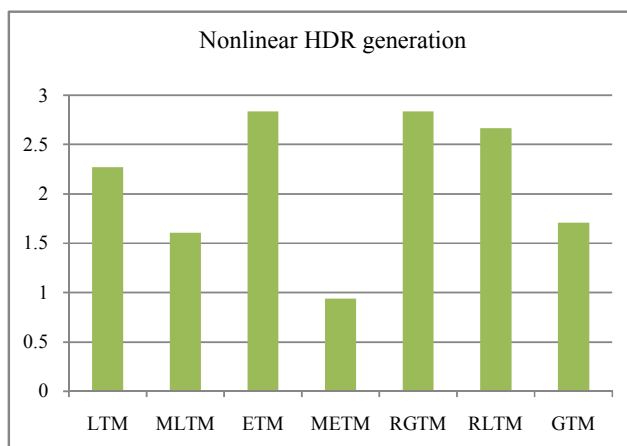


Fig. 2 Rating obtained for tone mapping for HDR images generated using nonlinear method

The HDR images obtained by the linear production techniques have better quality than the one achieved by the nonlinear one. The images obtained by the nonlinear technique are very greenish and they lost the details of the bright and dark regions as it is clear in the fourth image of Fig. 7.

VI. CONCLUSION

This paper presented a subjective evaluation of various tone generation and tone mapping techniques who rated these images. The evaluation has been conducted by twelve observers who rated these images based on its visual pleasures. HDR images are generated from a sequence of differently exposed images using either a linear and nonlinear combination technique. Linear HDR generation produces images with better quality and more visually pleasing than the nonlinear ones. Among the studied tone mapping methods, Reinhard et al. algorithms (RGTM and ELTM) have the best results alongside the exponential tone mapping (ETM).

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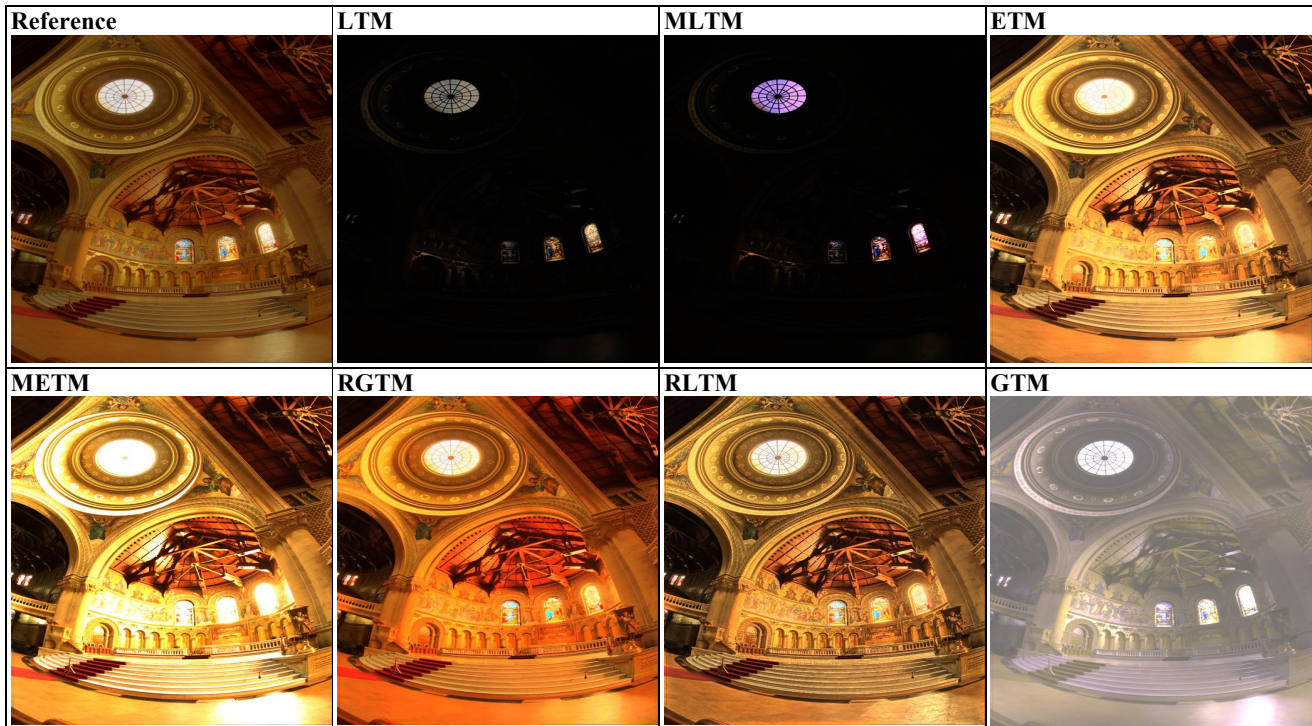


Fig. 4 Results of tone mapping algorithm for HDR image obtained from

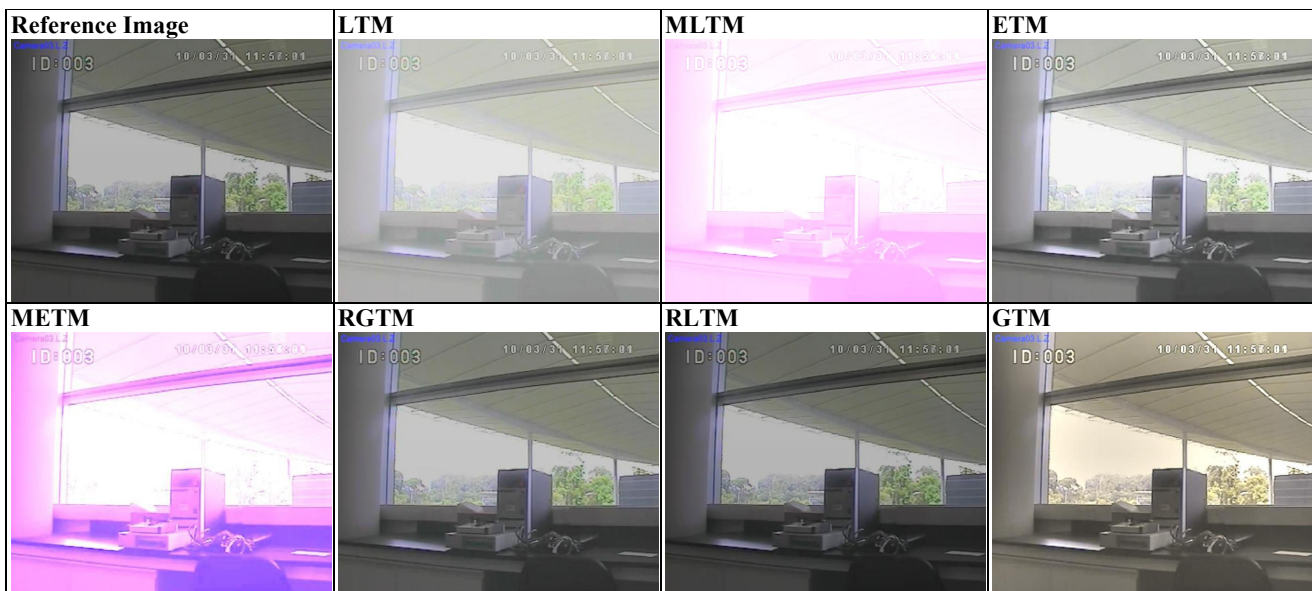


Fig. 5 Results of tone mapping algorithm for HDR image obtained using linear HDR generation method

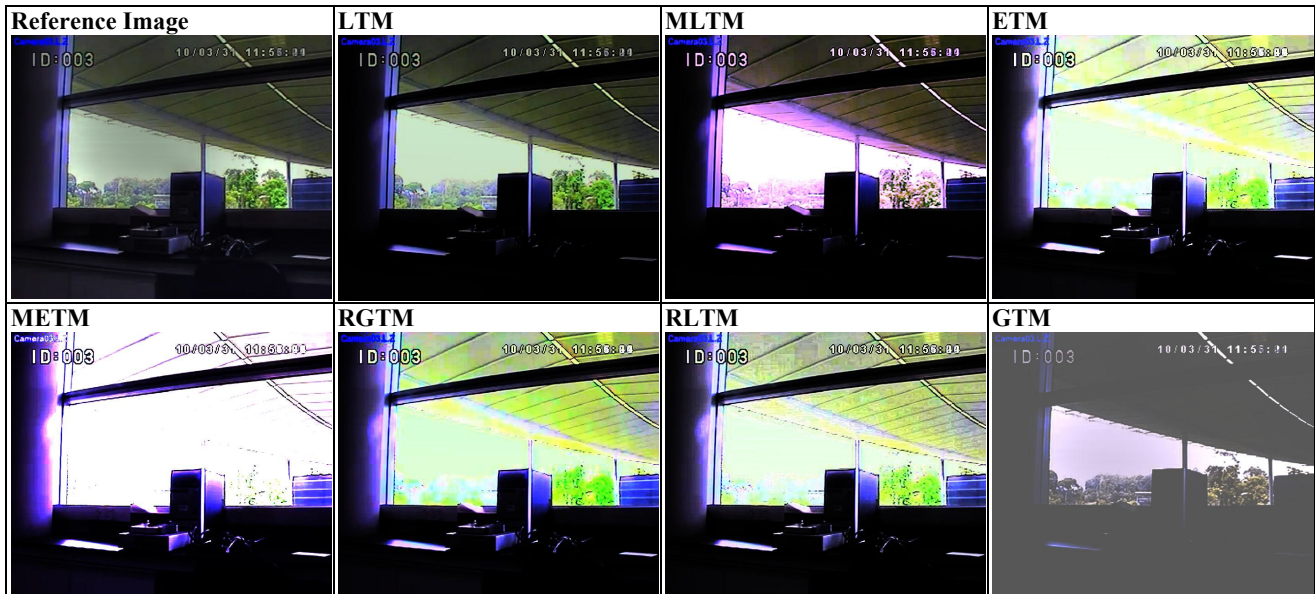


Fig. 6 Results of tone mapping algorithm for HDR image obtained using nonlinear HDR generation method

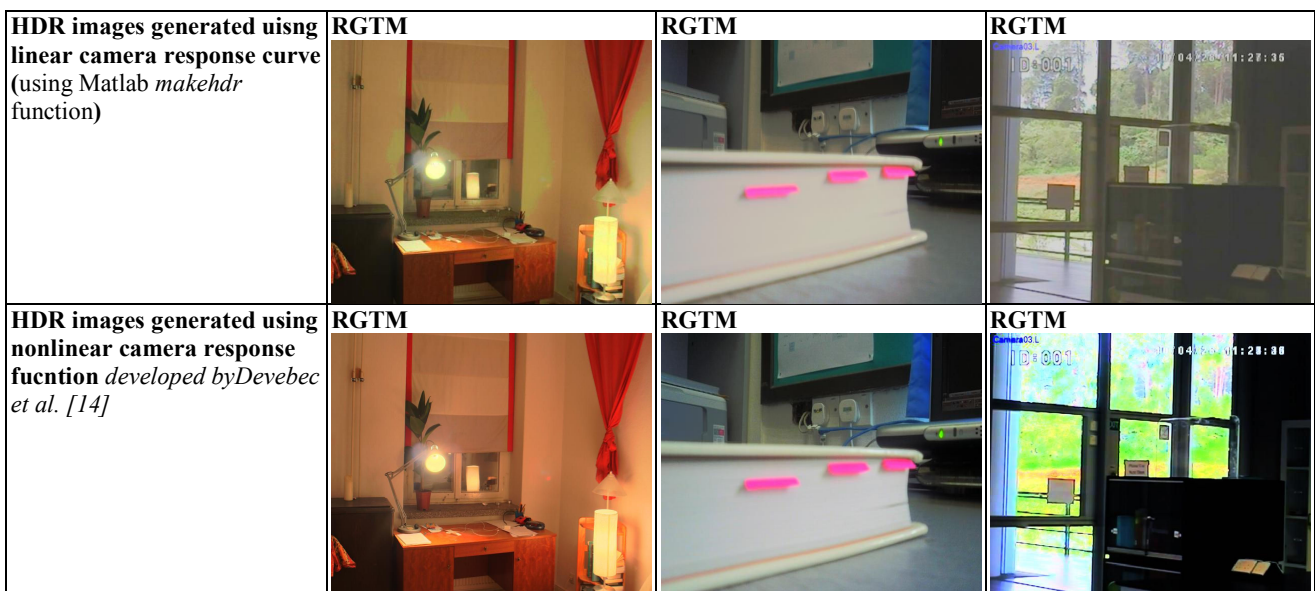


Fig. 7 Comparison between linear and nonlinear generation of HDR images using the Reinhard et al. tone mapping algorithm