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High-dynamic range image generation from single low-dynamic range image

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Abstract: Due to the growing popularity of high-dynamic range (HDR) image and the high complexity to capture HDR image, researchers focus on converting low-dynamic range (LDR) content to HDR, which gives rise to a number of dynamic range expansion methods. Most of the existing methods try their best to tackle highlight areas during the expanding, however, in some cases, they cannot achieve approving results. In this study, a novel LDR image expansion technique is presented. The technique first detects the highlight areas in image; then preprocesses them and reconstructs the information of these regions; finally, expands the LDR image to HDR. Unlike the existing schemes, the proposed approach escapes the complicated treatment to highlight areas in the process of expansion, which makes the expansion straightforward; at the same time, it facilitates the expansion scheme and minimises the formation of the artefacts. The experimental results show that the proposed method performs well; the tone mapped versions of the produced HDR images are popular. The results of the image quality metric also illustrate that the novel approach can recover more image details with minimised contrast loss and reversal, compared with the existing schemes considered in the comparison.

1 Introduction

Along with the emergency of high-dynamic range (HDR) image sensors and display devices, researchers have focused on HDR image processing, including capturing, coding, compression, displaying and so on [1]. HDR display is capable of providing a rich visual experience, video or image displayed on them looks more natural and preferential. The development in HDR hardware and display technique indicates that HDR display devices will become commonplace in the near future in most fields, from entertainment to scientific visualisation.

However, capturing HDR images or videos directly is not as easy as capturing low-dynamic range (LDR) originals [2], it requires specialised equipment to automate. This has led to research on providing HDR content from LDR content, which not only obtains HDR images by the existing consumer cameras, but also makes it possible to re-use the large amount of already existing legacy contents on HDR monitor. This need to expand the range of LDR image or video to create HDR depiction which matches real-world luminance values as faithfully as possible.

In general, at image or video capturing moment, professionals (photographers, movie/video markers) try to avoid excessive highlight because it distracts and obscures surface details. However, it is unavoidable that there are highlights in image for some applications in practice. Most of the existing image expansion methods make a general assumption that highly saturated pixels need to be expanded much more than the rest. As a result, bright image areas representing features such as highlights, or the sun in the sky, are largely boosted, thus sometimes results in contouring artefacts for bright objects [3]. On the other hand, in some applications, such as photography, movie, video, object segmentation and recognition, highlight makes image unnatural and leads to false results. So, for pleasant entertainment or better processing, it is necessary to explore a dynamic range expansion method that can have the image without highlights.

However, it is very complex to get rid of the highlight in the process of expansion, moreover, it will induce artefacts. Thus, in this paper, we propose an expansion method that not only obtain images without highlights, but also avoids settling highlights in expanding procedure. Its most important novelty is the fashion used for expanding the highlight areas, which is different from the existing algorithms. In the proposed scheme, the highlight areas processing is separated from the dynamic range expanding step. This novelty escapes special treatment to highlight areas in the process of expansion and facilitates the dynamic range expansion step. Moreover, the novelty not only minimises the formation of the artefacts introduced by the special treatment to highlight areas used in other existing algorithms, but also brings effective dynamic range expansion and high quality HDR images. The proposed approach first decomposes the image into highlight areas and non-highlight areas; then preprocesses the highlight areas to make the image natural and proper; finally, based on the preprocessing result, an efficient expansion step is conducted on the LDR image to generate the HDR image.

This paper is organised as follows: The related researches are introduced in Section. 2. In Section. 3, the mathematical model of the proposed approach is illustrated. Selected representative results of a comprehensive experimental evaluation are given in Section. 4. Conclusions and further discussions are presented in the last section.

2 Related work

Daly and Feng [4, 5] firstly addressed the problem of dynamic range expansion by bit-depth extension techniques and de-contouring methods. However, their schemes expand image into 10-bits per colour channel per pixel, which is lower than that of HDR image can carry. Afterwards, researchers have presented several dynamic range expansion algorithms; reader can read the review paper [6]. These algorithms can be regrouped in four categories: global processing, classification and interactive method, expand-map approach and technique similar to HDR image capturing.

Landis [7] proposed the first global expansion method, which applied an exponential function for pixel values above certain threshold to expand LDR images. This method works primarily for image-based lighting, but not well for visualising HDR images. Then, Akyuz *et al.* [8] performed two experiments which reveal that in many circumstances a linear contrast scaling works surprisingly well for mapping LDR content onto HDR screens, suggest that simple solutions may suffice for LDR expansion. Afterwards, Masia *et al.* [3] presented a simple expansion method based on γ transformation, which expands the whole image with a same γ value.

Meylan *et al.* [9, 10] classified image into specular highlight component and diffuse component, applying a steep linear tone mapping curve to the highlight component and a mild linear curve to the diffuse component. This method is not very good at reproducing small highlight area such as isolated highlight. In addition, Didyk *et al.* [11] gave a more sophisticated classification for bright areas in the image. They segmented the image into diffuse surfaces, light sources and specular highlight reflections. Different expansion functions were applied to light sources and specular highlight reflections. This method is suitable for high quality video enhancement thanks to the temporal coherence of the segmentation and the expansion function. It is interactive and relies on user's assistance to guide the process. Furthermore, Masia *et al.* [12] also proposed a classification method that divides the image into objects of interest and background, different expanding method can be used for each region. They also focused on an interactive approach where the user guides the expansion process.

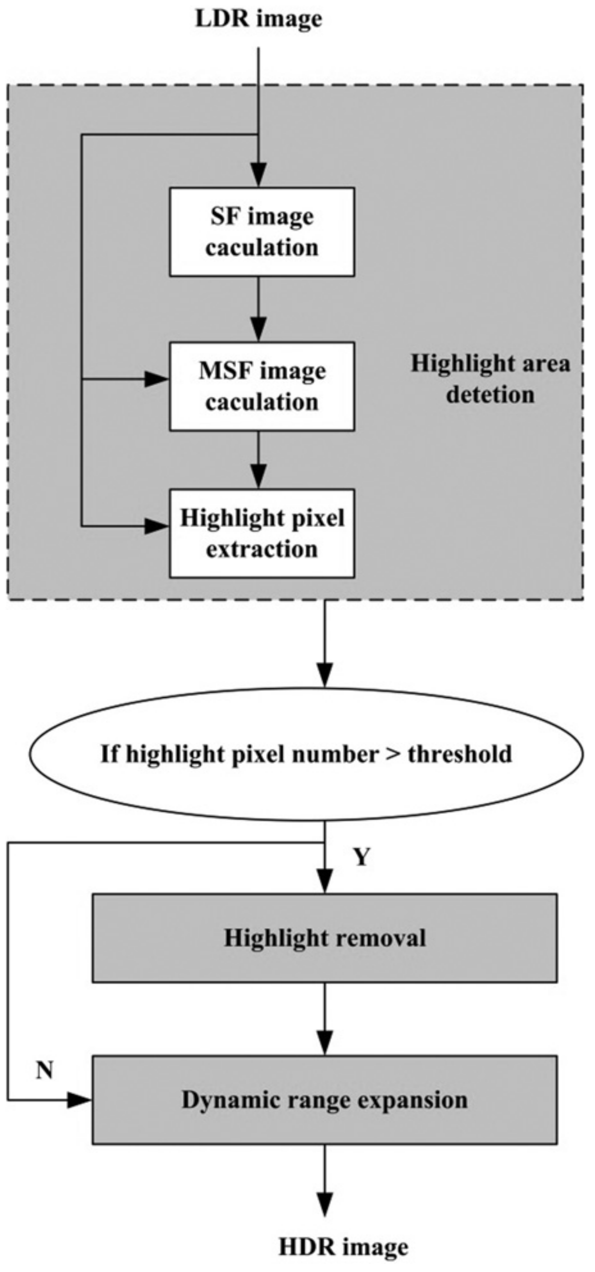

Fig. 1 *Structure of the proposed method*

Banterle *et al.* [13, 14] proposed a general framework for expanding LDR content for HDR monitor. They computed an expand-map to reconstruct the lost luminance profiles in high luminance areas of the image and attenuate quantisation or compression artefacts that can be enhanced during expansion. This framework has been extended to video by designing a temporally-coherent version of the expand-map [15]. Rempel *et al.* [16] also presented an expand-map approach. In their scheme, first, the image is filtered to remove artefacts due to the compression algorithms of the media. Then, the image intensity is linearised and a binary mask is computed by thresholding of the saturated pixels; a brightness enhancement map is computed in real time as a blurred version of the binary mask, combined with an edge stopping function to retain contrast of prominent edges. Finally, the contrast of the LDR image is scaled according to the enhancement map. Thereafter, Kovaleski and Oliveira [17] presented a dynamic range expansion technique that is also based on real-time computation of a brightness enhancement function, but substitutes a bilateral filter for the combination of a Gaussian blur and an edge stopping function used in Rempel *et al.*'s algorithm.

Wang and Chiu [18] proposed an LDR expansion method similar to HDR image capturing technique. The HDR image is also generated by multiple LDR images, whereas these LDR images do not come from multiple exposure images by camera, but come from one LDR image. They first generate multiple LDR images from the original input LDR image using an exposure-dependent *S* curve; then fuse these images into one virtual real scene HDR image with wide dynamic range. This method is under the assumption that the original LDR image is optimised in its brightness.

Most of the expansion methods described above try their best to specially handle the highlights in the process of expansion. In contrast with these methods, the proposed approach focuses on eliminating the influence of highlights before expanding. It carries out the highlight process and dynamic range expansion separately; thus, the sophisticated dispose to highlight areas is avoided from expanding, which makes the method succinct and efficient.

3 Proposed method

In this section, the proposed approach is described. Its framework is shown in Fig. 1. The scheme mainly contains three stages: highlight areas detection, highlight areas processing and dynamic range expansion. The details will be described in the following sections.

3.1 *Highlight area detection*

In this stage, the highlight areas are detected based on the difference between the original image and the modified specular free (MSF) image [19, 20]. The MSF image is obtained by adding the mean of the minimum of red, green and blue (RGB) colour value of the original image to the specular free (SF) image as shown in (1). The SF image is calculated by subtracting the minimum of RGB colour value in each pixel level, thus at least one element of the SF image pixel is 0. Compared with the SF image, the colour appearance of the MSF image is closer to that of the original image, which can be seen from Fig. 2.

$$\mathrm{MSF}_i(x, y) = \mathrm{SF}_i(x, y) + \bar{I}_{\min} \quad (1)$$

where $i \in \{r, g, b\}$, $\mathrm{SF}_i(x, y) = I_i(x, y) - \min(I_r(x, y), I_g(x, y), I_b(x, y))$. $I_i(x, y)$ is the value of the ith colour channel at (x, y) pixel position of the original image $\boldsymbol{I}$, $\bar{I}_{\min}$ is the mean of the minimum value $I_{\min}(x, y) = \min(I_r(x, y), I_g(x, y), I_b(x, y))$ for all the pixels in the image.

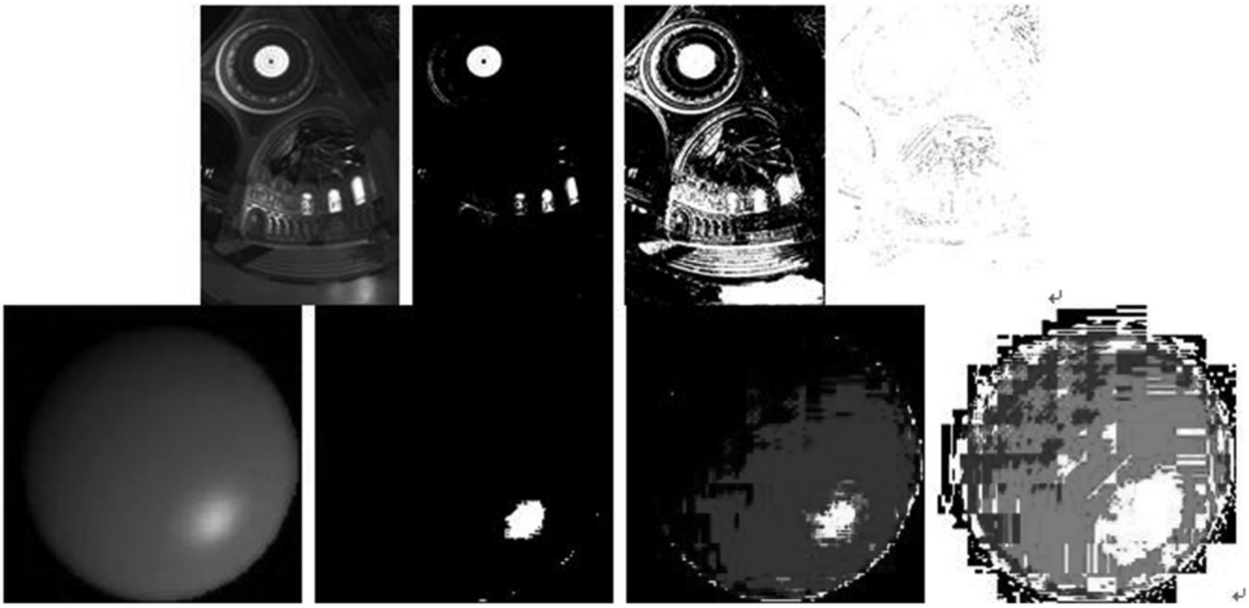

Fig. 2 *In each row, from left to right: original image, detected highlight areas, difference image between original image and MSF image, difference image between original image and SF image*

The difference between the original image and MSF image is used to detect highlight areas

$$\text{pixel} \in \begin{cases} \text{highlight}, & \text{if } d_i(x, y) > \text{ th for all } i \\ \text{others}, & \text{otherwise} \end{cases} \quad (2)$$

where $d_i(x, y) = I_i(x, y) - \text{MSF}_i(x, y)$, th is the threshold, its value is found for each image by Nobuyuki Otsu (OTSU) method adaptively. Fig. 2 shows the detected highlight image and the difference images between the original image and the SF, MSF image.

3.2 Highlight area processing

After detecting highlight areas, the highlight removal technique is used to process them. The highlight removal technique is an essential subject in the field of computer vision [21, 22]. Most of the highlight removal methods depend on the dichromatic reflection model introduced by Shafer [23]. These methods need colour segmentation and image normalisation. We would like to perform highlight removal without using luminance information. Thus, a method based on principal component analysis [19] is chosen.

Since there are three colour channels, RGB image can be represented by three principal components weighted by three eigenvectors as

$$\boldsymbol{I} = \boldsymbol{V}_1\boldsymbol{P}_1 + \boldsymbol{V}_2\boldsymbol{P}_2 + \boldsymbol{V}_3\boldsymbol{P}_3 \quad (3)$$

where $\boldsymbol{I}$ is the RGB value of image, $\boldsymbol{V}_i$ and $\boldsymbol{P}_i$ are the principal component vectors and corresponding principal components, respectively. It has been proven by experiments that in most cases, the second principal component corresponding to the second largest eigenvalue contains the part or whole of the highlight component [19]. Sometimes it is not true, thus, a threshold value should be set to detect whether the second largest principal component contains highlight component or not. Before this, the fidelity ratio FR_i need to be defined as

$$\text{FR}_i = \frac{\sigma_i}{\sum_{j=1}^{3} \sigma_j} \quad (4)$$

where σ_i is the ith eigenvalue.

Fig. 3 *From left to right: original image I, highlight removal image without and with combination step*

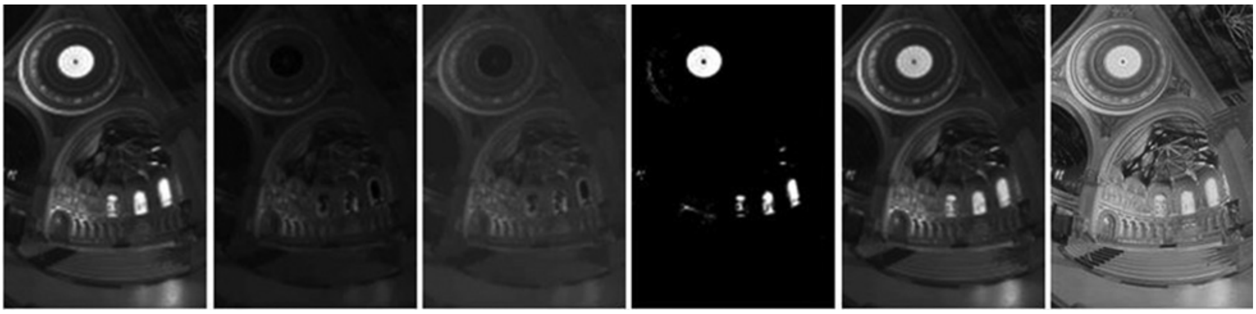

Fig. 4 *Proposed expansion method result illustration. From left to right: input LDR image, SF image, MSF image, detected highlight areas, highlight removal image and tone-mapped version of our HDR output image (tone-mapped using Reinhard's TMO [25])*

Fig. 5 *Some original test images. From left top to right down: fish, arm, tree, teapot, T-ball, ttele, ball, face, church, sunset and plane*

If $FR_2 < \textit{threshold value}$, the second principal component is detected as highlight component, then it will not be used in image reconstruction. According to the experiments, the threshold is set to 0.02 [19].

In experiments, it was found that the first principal component still contains some highlight part. For eliminating the highlight remained in the first principal component, histogram equalisation is applied to the first principal component. The reconstructed image can be expressed as

$$\boldsymbol{I}_{\mathrm{R}} = \boldsymbol{V}_1\boldsymbol{P}_{\mathrm{h}} + \boldsymbol{V}_2\boldsymbol{P}_2 + \boldsymbol{V}_3\boldsymbol{P}_3 \quad (5)$$

where $\boldsymbol{P}_{\mathrm{h}}$ is the histogram equalised principal component and $\boldsymbol{I}_{\mathrm{R}}$ is the reconstructed image. The middle part of the right side is included or removed in reconstruction according to the fidelity ratio of the second largest eigenvector.

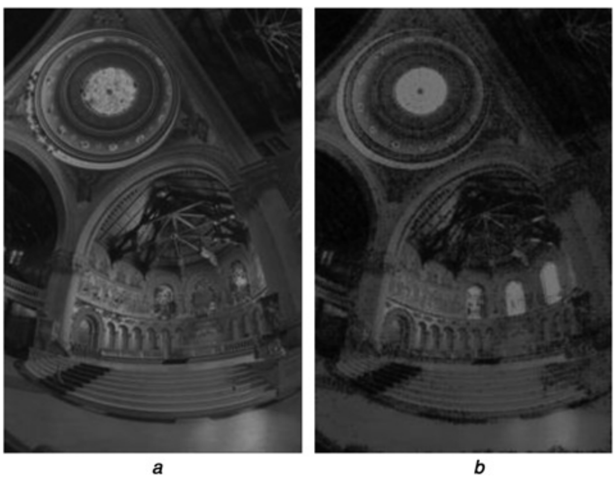

Fig. 6 *Metric results*

a Comparison of the original LDR image with the highlight area processed LDR image
b Comparison of the original LDR image with its HDR image generated by our method

From the results, it was noted that the colour of the reconstructed image $\boldsymbol{I}_{\mathrm{R}}$ is shifted. The original colour of the image without highlight is obtained by using second order polynomial transformation. The main problem is to find the weight function for the polynomial transformation. The weight function is calculated using transformation between the detected non-highlight part of the original image and corresponding part of the reconstructed image as shown in (6)

$$\boldsymbol{I}_{\mathrm{d}} = \boldsymbol{W}\boldsymbol{M}_{\mathrm{d}} \quad (6)$$

The weight function $\boldsymbol{W}$ can be obtained by using the least square pseudo inverse matrix calculation

$$\boldsymbol{W} = \boldsymbol{I}_{\mathrm{d}}\left[\boldsymbol{M}_{\mathrm{d}}^{\mathrm{T}}\boldsymbol{M}_{\mathrm{d}}\right]^{-1}\boldsymbol{M}_{\mathrm{d}}^{\mathrm{T}} \quad (7)$$

where $\boldsymbol{I}_{\mathrm{d}}$ is the detected non-highlight part in the original image, $\boldsymbol{M}_{\mathrm{d}}$ is the second order polynomial extension of corresponding part of the reconstructed image. $[]^{-1}$ and $[]^{\mathrm{T}}$ are the inverse and transpose of matrix, respectively.

Employing the weight function to the second order polynomial extension $\boldsymbol{M}$ of the reconstructed image $\boldsymbol{I}_{\mathrm{R}}$ as shown in (8) can obtain highlight removal image $\boldsymbol{I}_{\mathrm{Diff}}$ of the original image $\boldsymbol{I}$.

$$\boldsymbol{I}_{\mathrm{Diff}} = \boldsymbol{W}\boldsymbol{M} \quad (8)$$

In the experiments, it was found that the colour of image $\boldsymbol{I}_{\mathrm{Diff}}$ is not exactly the same as the original image $\boldsymbol{I}$, sometimes the colour difference between $\boldsymbol{I}_{\mathrm{Diff}}$ and $\boldsymbol{I}$ is very obvious. For eliminating the colour difference, we combine images $\boldsymbol{I}$ and $\boldsymbol{I}_{\mathrm{Diff}}$ to obtain the final highlight removal image $\boldsymbol{I}_D$

$$I_D(x, y) = k_{xy}I(x, y) + (1 - k_{xy})I_{\mathrm{Diff}}(x, y) \quad (9)$$

where k_{xy} is the coefficient of pixel at (x, y) position, which takes value 0 or 1, depending on whether the pixel at (x, y) position is highlight pixel ($k_{xy} = 0$) or not ($k_{xy} = 1$).

Fig. 3 shows the original image $\boldsymbol{I}$, images $\boldsymbol{I}_{\text{Diff}}$ and $\boldsymbol{I}_D$. From the figure, it can be seen that the colour of image $\boldsymbol{I}_D$ is the same as that of the original image $\boldsymbol{I}$; the colour of image $\boldsymbol{I}_{\text{Diff}}$ has obvious difference to the original image $\boldsymbol{I}$, especially in the second row. From the images in right column, it was also noted that image $\boldsymbol{I}_{\text{Diff}}$ has artefacts that make the image unnatural; instead, the combined image $\boldsymbol{I}_D$ has no artefacts and looks natural.

3.3 Dynamic range expansion

Akyuz *et al.* [8] got a result through two experiments: LDR image does not necessarily require sophisticated treatment to produce a compelling HDR experience. Simply boosting the range of an LDR image linearly to fit the HDR display can equal or even surpass the appearance of a true HDR image. However, this result is obtained based on the assumption that the LDR image has proper exposure, and it is not always true if the image contains highlight area. In our algorithm, we preprocess the highlight areas before expansion to make the image a properly exposed one. Thus, the image is boosted linearly according to (10) [8]

$$L_{\text{h}} = I_{\text{h}}\left(\frac{L - L_{\min}}{L_{\max} - L_{\min}}\right)^{\gamma} \tag{10}$$

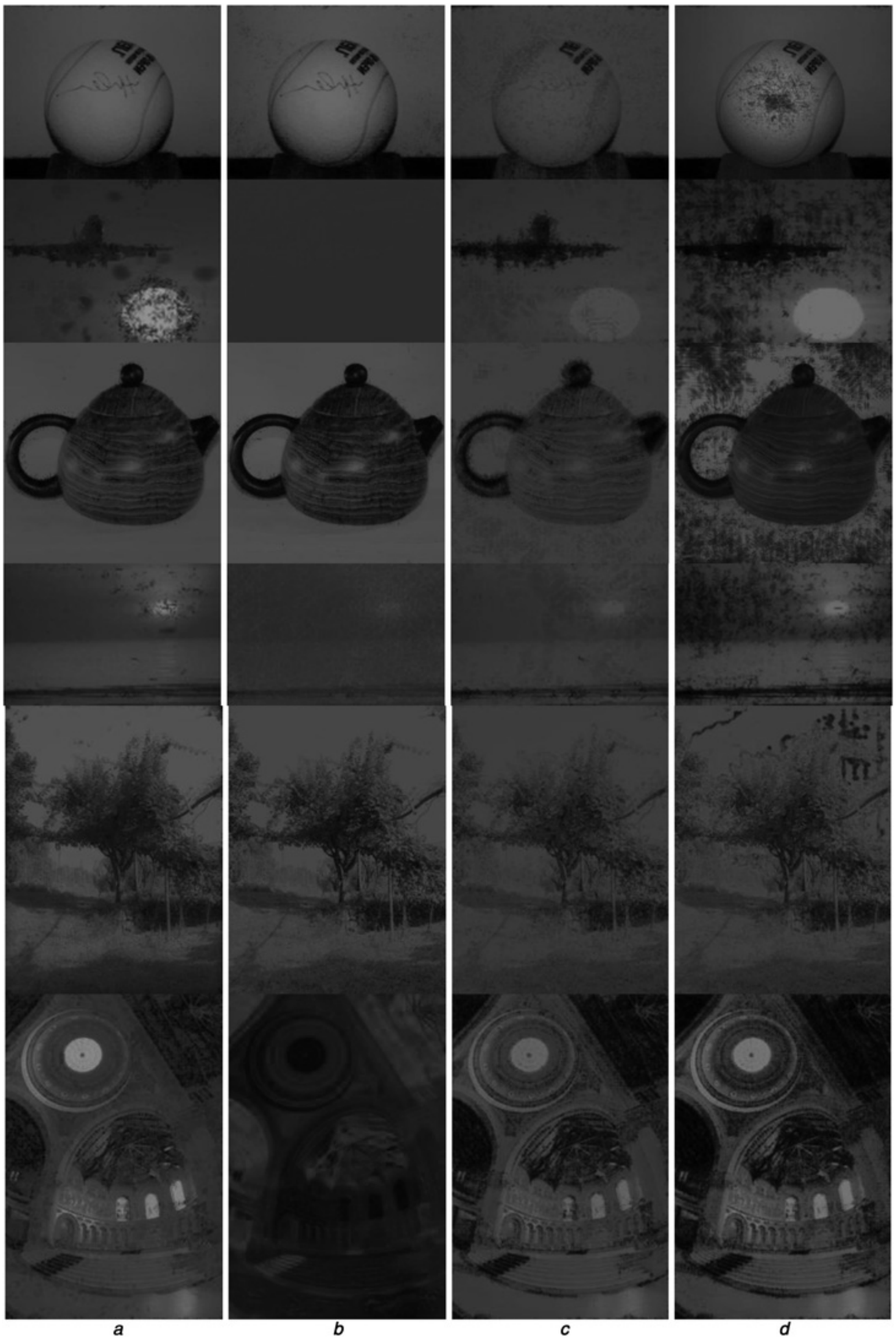

Fig. 7 *Metric results of four algorithms*
a iPG
b γ expansion
c LDR2HDR
d Proposed scheme

where L is the luminance of the pixel being scaled, L_{min} and L_{max} are the minimum and maximum luminance of the LDR image after highlight removal, I_h is the maximum input intensity of the HDR display, and γ determines the non-linearity of the scaling. This operation was applied to all pixels individually. The exponent γ determines how the mean luminance of the image will change relative to other pixels. For $\gamma = 1$ all pixels will be scaled equally, whereas for $\gamma > 1$ the mean luminance will be relatively darker and for $\gamma < 1$ it will be relatively lighter. In our experiments, we take $\gamma = 1$.

Meylan and others compared their five kinds of tone scales and linear scale {cf. image (f) in Fig. 11 of [9]}. The result shows that, when highlight area is too small, such as smaller than 0.01% of the total image pixel number, the performance of linear stretch is best. Thus, after detecting highlight areas, the percentage of highlight pixels in image will be compared with a threshold. If the percentage is smaller than the threshold, the image is boosted linearly without highlight area processing. Therefore, our method can choose adaptively whether preprocess highlight areas or not according to percentage of highlight pixel number. Fig. 4 displays an example of result images of each stage in the proposed method (see also Fig. 1).

4 Experiments and results

We compare the proposed approach with Banterle's tone photographic mapping (iPG) [14], Masia's γ expansion method [3] and Rempel's LDR2HDR [16]. All the compared algorithms are implemented with Matlab2011b on Intel Core i5–2520M CPU @ 2.5 GHz, 4.00 GB RAM, win32 system. The threshold in highlight area detection is found by the OTSU method adaptively. The maximum illumination of HDR display is set to 3000cd/m^2, according to the Brightside's 37' HDR monitor.

A set of images are used for testing and verifying the algorithms, some of the images come from the COREL and CALTECH-256 databases. Fig. 5 shows a subset of the tested images, each of them contains highlight areas with different highlight pixel number. For example, the highlight pixel number percentage of the first image in the bottom row is lower than the threshold, thus, this image is expanded without highlight area processing.

4.1 Highlight processing results

To test if the highlight area processing works well and whether it introduces artefacts or not, the original LDR image is compared with LDR image after highlight processing and its corresponding HDR image generated by the proposed method, respectively, using a novel image quality metric which operates with arbitrary dynamic ranges [24].

The image quality metric can detect three types of distortions, which are expressed by different colours: red, green and blue that identify contrast reversal (the contrast polarity is reversed in the test image with respect to the reference image), loss of visible contrast (visible contrast in the reference image becomes invisible in the test image) and amplification of invisible contrast (not visible in the reference image and visible in the test image), respectively. The compared images are shown in Fig. 6, the reference images are the original LDR images. Referring to the detected highlight images in Fig. 2, from Fig. 6*a*, it can be seen that the highlight processing indeed process and only processes the highlight areas. From Fig. 6*b*, it was found that there is no loss and reversal of contrast in the highlight areas between the HDR image generated by the proposed approach and the original LDR image. This means that the highlight processing does not introduce artefacts to the generated HDR image.

The high performance of the highlight processing owes to the illumination consistency of image in the process and the combination step formulated by (9). This step guarantees that the image after highlight processing is totally the same to the original image except the highlight areas.

4.2 Metric results

The image quality metric is also used to compare the proposed method with other three algorithms. The metric results of four schemes are shown in Fig. 7.

Referring to the original image, it is obvious that the details in the areas of the original images corresponding to that in the areas coloured blue in our metric result images are invisible, whereas they become visible after expanded by the proposed method. Furthermore, the metric results show that there are more blue pixels in our metric images than in other three algorithms' metric images, which means that the proposed approach can reveal more image details. Fig. 7 also indicates that all compared algorithms induce little contrast reversal (red pixel) and contrast loss (green pixels), but they are negligible. Since γ expansion focuses on expanding images with large saturated regions, its performance is undesirable for some test images that are not largely saturated. Thus, the rebarbative metric image of γ expansion suffers from the low key value of the test image.

To emphasise the performance of the compared algorithms, we compute the red, green and blue pixel percentages (the ratio of the red/green/blue pixel number to the total image pixel number) of the metric images obtained by the image quality metric. These numerical results are listed in Table 1, they also imply that the proposed approach can arouse more image visibility and induce little contrast loss and reversal in average.

The metric results of the experiments show that our scheme amplifies more contrast in the most significant areas of the images than other three schemes, with little objectionable artefacts and contouring artefacts at the edges of bright objects. These artefacts are usually introduced by the use of different expansion methods to the highlight and non-highlight areas, and largely boosting to the bright objects. However, unlike the algorithms considered in our experiments, based on the highlight processing, the proposed approach expands the highlight and non-highlight areas using the

Table 1 Red, green and blue pixel percentages of HDR metric images: larger blue percentage indicates more detail reveal; larger red percentage means more contrast reversal; and larger green percentage denotes more contrast loss

	iPG			γ expansion			LDR2HDR			Proposed		
Images	Red %	Green %	Blue %	Red %	Green %	Blue %	Red %	Green %	Blue %	Red %	Green %	Blue %
fish	1.070	1.120	94.48	82.15	7.140	10.47	11.72	7.690	80.55	7.210	0.020	92.70
arm	1.680	2.360	22.30	62.76	37.04	0.000	0.080	47.74	0.600	1.070	3.130	45.25
tree	5.260	9.670	7.360	6.350	6.680	23.37	12.02	51.10	3.910	0.116	0.302	0.162
teapot	1.960	0.630	24.15	0.550	0.270	31.78	10.06	46.41	5.320	5.410	1.300	56.64
t-ball	1.230	0.170	22.16	0.630	0.130	40.97	4.310	53.68	13.28	1.410	0.970	23.90
stele	30.35	26.45	22.94	4.250	95.56	0.005	44.60	17.39	24.32	33.51	3.210	59.53
ball	27.42	2.510	41.48	29.47	49.62	19.38	37.88	14.65	32.33	8.060	0.019	78.69
face	3.940	5.080	34.05	100.0	0.000	0.000	2.950	9.570	45.64	4.320	0.068	89.84
church	3.290	17.36	29.92	98.18	1.730	0.000	5.900	15.02	52.10	4.690	3.240	73.58
sunset	2.580	5.270	10.52	0.160	99.64	0.150	1.210	60.27	4.000	0.390	0.270	71.64
plane	7.410	15.40	22.27	0.000	100.0	0.000	3.850	42.40	11.10	1.820	0.440	75.59
average	**7.835**	**7.820**	**30.15**	**34.95**	**36.16**	**11.47**	**12.23**	**33.27**	**24.83**	**6.182**	**1.179**	**60.68**

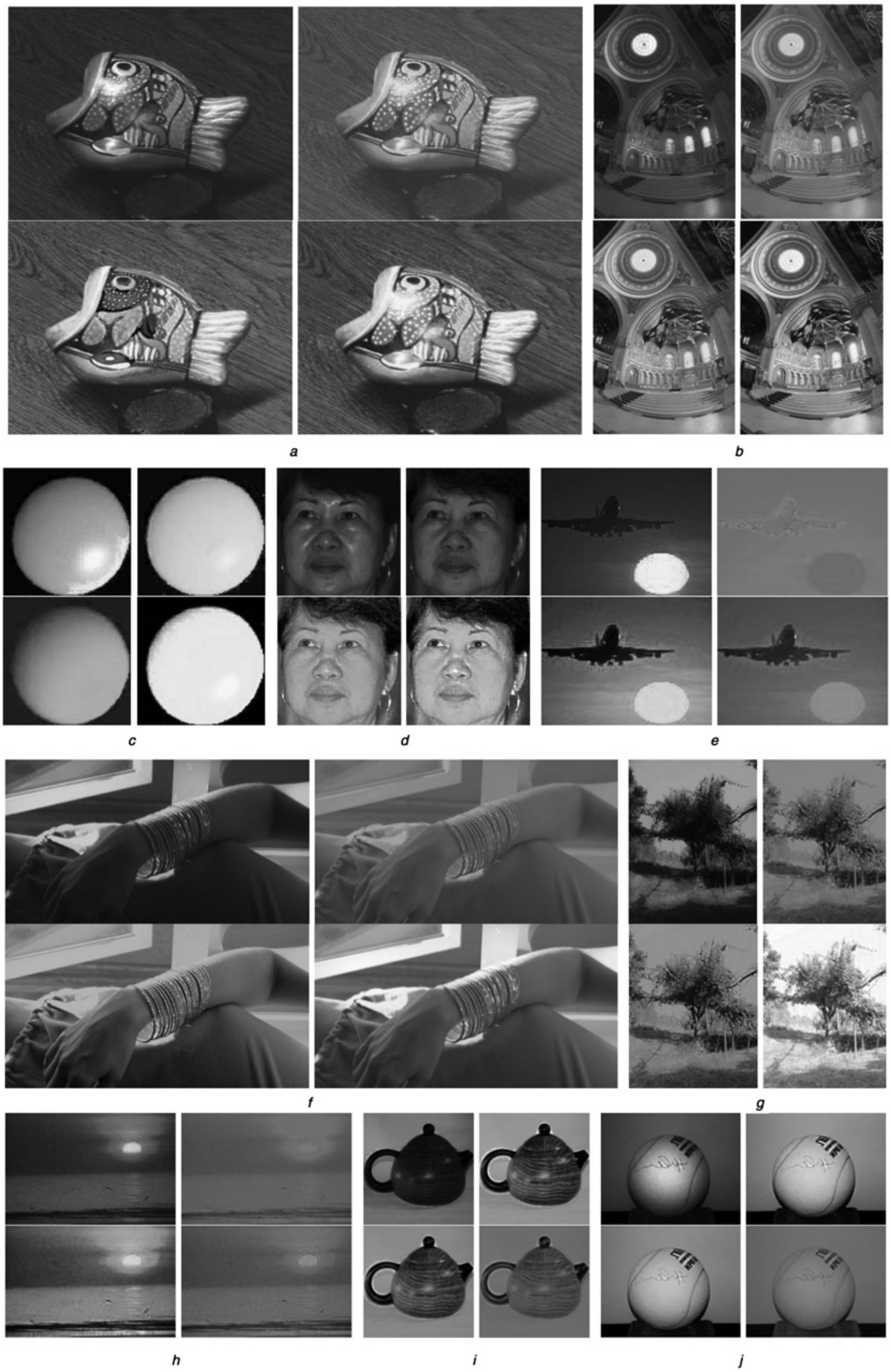

Fig. 8 *Tone mapped versions of four algorithms; for each image group, from the top left in clockwise order: iPG [14]; γ expansion [3]; LDR2HDR [16]; proposed method (all tone-mapped version produced using Reinhard's TMO [25])*

a Tone mapped versions of the original image fish
b Tone mapped versions of the original image church
c Tone mapped versions of the original image ball
d Tone mapped versions of the original image face
e Tone mapped versions of the original image plane
f Tone mapped versions of the original image arm
g Tone mapped versions of the original image tree
h Tone mapped versions of the original image sunset
i Tone mapped versions of the original image teapot
j Tone mapped versions of the original image T-ball

same mathematical model, which minimises the probability of the formation of those artefacts. Furthermore, the proper techniques for highlight areas guarantee the effect of the image preprocessing, which favours the high quality of the generated HDR images.

4.3 Tone mapped versions

The generated HDR images cannot be presented here directly, due to the limitations of the print medium. For intuitively testing and comparing the proposed method with other three algorithms, the generated HDR images are compressed with photographic tone mapping operator [25] and are shown in Fig. 8. These tone mapped images imply that, the proposed method can totally eliminate the highlights induced by specular reflection, as Figs. 8*a*, *c* and *d*; it makes the glaring highlight induced by light source more soft and comfortable, as Figs. *b*, e, f and h. Moreover, it exposes some details and makes them visible, as Figs. 8*a* and *b*.

In brief, these tone mapped images indirectly suggest that the proposed scheme performs well; it makes the image containing highlight areas more popular and proper for entertainment and surveillance applications than other three algorithms. These advantages are attributed to the utilisation of highlight processing technique and the uniformity of the expansion method to the whole image.

5 Conclusions and perspectives

In this paper, we presented a novel approach for dynamic range expansion of legacy, low dynamic range images for viewing on HDR displays and generating HDR images.

The experiments show that the proposed method makes image more favourable and natural, more proper for applications such as image segmentation, image recognition, video surveillance and so on. The image quality metric results also illustrate that the proposed method works well and generates high-quality HDR images. The good performance of the novel approach benefits from the fashion that deals with the highlight expansion. Unlike some existing expansion methods, the proposed scheme does not do any sophisticated treatment to the highlight in the process of expansion, but processes it before expanding. This suppresses the formation of the artefacts and assures the quality of the generated HDR images.

Using the proposed framework, the processing speed is mainly determined by the highlight removal stage. Although we introduced a strategy to choose whether remove the highlight areas or not adaptively according to the percentage of highlight pixel number, the actual speed is not suitable for real-time processing. In the future, we would like to explore other high efficiency highlight removal techniques to improve the processing speed. Furthermore, we also want to optimise our algorithms and implement them on hardware embedded system to accelerate the processing time.

6 Acknowledgments

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