Image acquisition technique for high dynamic range scene using multiband camera

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ABSTRACT

For the accurate colour reproduction, multiband cameras have been studied and developed. On the other hand, high dynamic range image acquisition is also strongly desired in many applications. A multiband camera has a potential to meet both needs if its sensitivities are properly controlled. In this paper, a method for expansion of dynamic range that uses a six-band camera consisting of three high sensitive bands and three low sensitive bands is introduced. Experimental results demonstrating the effectiveness of the presented method is also shown.

1. INTRODUCTION

The quality of digital colour image depends on several factors such as image resolution (or image size, i.e. the number of pixels), colour reproduction, tone reproduction, noise characteristics, etc. In terms of colour reproduction, multiband imaging techniques have been studied by many research groups [1-7]. As well as such groups, the natural vision project, one of national research projects of Japan, has also focused on the colour reproduction and has developed methods and systems for highly accurate colour reproduction[8-12]. For this purpose, as input devices, 16 band camera for still image and six-band camera for motion picture have been developed [11,12]. Though the multiband image acquisition is performed for accurate colour reproduction, it has the possibility of being applied to high dynamic range (HDR) image acquisition as well. Many techniques for HDR imaging have been proposed [13-16]. Typical ones are time-sequential image acquisition with different exposure time and the consequent image synthesis. However, such acquisition can hardly be applied to moving objects. We considered modifying the six-band camera slightly to achieve the HDR imaging.

2. METHOD
2.1 OPTICAL SETUP

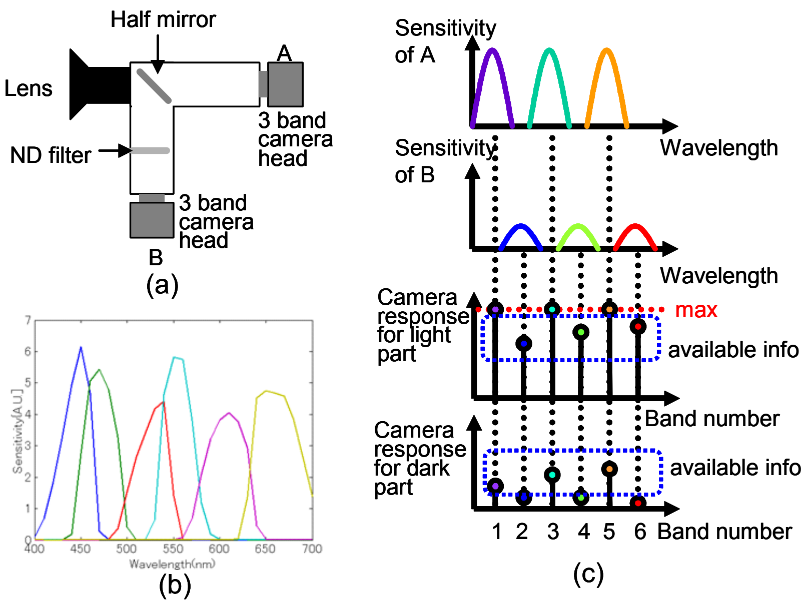


Figure 1: Six-band camera and sensitivity setting for HDR image acquisition. (a) Optical configuration of six-band camera. (b) Real spectral sensitivities of a six-band camera. (c) Schematic illustration of modification of sensitivities and the camera response for light and dark areas.

The six-band camera has a configuration shown in Figure 1(a). Light from the object is divided into two optical paths and captured by the different sets of three-band camera. By inserting a neutral density (ND) filter into one side optical path, we can differentiate the sensitivities. Top two rows of Figure 1(C) illustrate two sets of three-band characteristics. It is noted that spectral sensitivities of the real camera are not the same as shown in Fig. 1(c). For example, camera head A consists of band #1, #4 and #5 and the camera head B consists of the band #2, #3 and #6. In this paper, however, we assume the above-mentioned two sets of sensitivities for the sake of convenience.

2.2 BAND SELECTION AND SPECTRAL ESTIMATION

By the setting of spectral sensitivities mentioned above, the following function is expected. Namely, while for very light area in the scene the camera responses of high sensitive bands are saturated and give no information, those of low sensitive bands are in the dynamic range and give the significant information. On the contrary, while for very dark area, the camera responses of low sensitive bands are under the noise level, those of high sensitive bands are in the dynamic range. As this example, some bands function well for wide luminance range.

From the obtained camera responses, the spectral radiance is first estimated. The estimation is carried out based on Wiener estimation technique. Available bands for the spectral estimation depend on the pixel as mentioned above. For very dark area the band #1, #3 and # 5 are used and for very light area the band #2, #4 and #6 are used. Besides that, if more than three bands are available, those bands should be used. In the experiment, 15 combinations of band selection listed in Table 1 were used. Wiener estimation matrices for those combinations were generated in advance.

When different Wiener estimation matrices are applied pixel-by-pixel, the discontinuity of reproduced colour can take place. For this issue, the following technique was introduced. For the current pixel, the band selection category of neighbouring pixels in a certain area is counted. Then, weighted combination of related matrix estimation is applied to the current pixel. Namely, spectral estimate $\hat{\mathbf{f}}(\mathbf{r})$ at pixel position $\mathbf{r}$ is given by

$$\hat{\mathbf{f}}(\mathbf{r}) = \sum_{i=1}^{m} k_i \mathbf{W}_i \mathbf{g}_i(\mathbf{r}), \qquad k_i = n_i / n .$$

Here $\mathbf{g}_i$ and $\mathbf{W}_i$ denote multiband camera responses at $\mathbf{r}$ and the Wiener estimation matrix corresponding to ith band selection, respectively. m denotes the number of band selection set (in this paper, $m = 15$). n and n_i denote the total number of neighbouring pixels and the number of pixels of ith category, respectively.

Lightness of area	band number					
	1	2	3	4	5	6
very dark	○		○		○	
dark	○	○	○		○	
	○		○	○	○	
	○		○		○	○
	○	○	○	○	○	
	○		○	○	○	○
	○	○	○	○	○	
intermediate	○	○	○	○	○	○
light	○	○		○	○	○
		○	○	○	○	○
	○	○	○	○		○
		○		○	○	○
		○	○	○		○
	○	○		○		○
very light		○		○		○

Table 1: List of bands used for HDR multiband imaging.

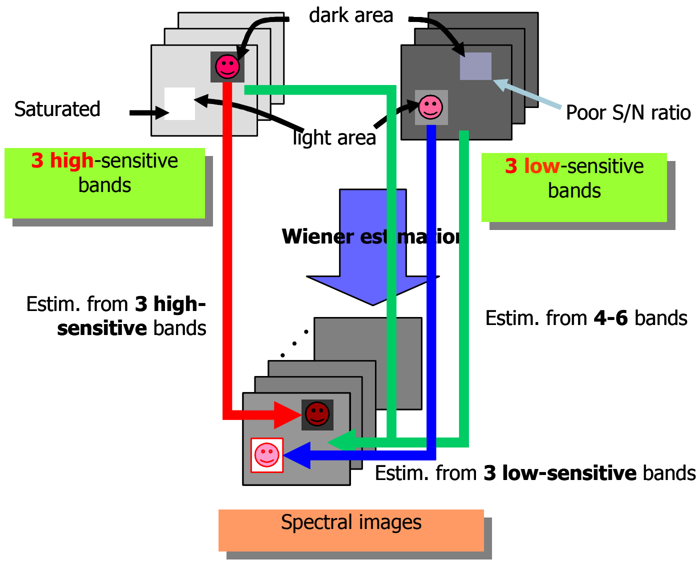


Figure 2: Schematic illustration of pixel-wise spectral estimation from available band response.

3. EXPERIMENT AND RESULTS
3.1 EXPERIMENT

In a laboratory, high dynamic range scene was intentionally produced. A picture of the object is shown in Fig. 3. In an observation booth, two sets of objects were set. Each set consisted of a Macbeth colour checker and a doll. One set was covered by a corrugated carton so that the intensity of illumination was significantly low compared with the other set. The six-band multiband camera developed in the Natural Vision project was used. In the experiment, instead of using ND filter, we captured the object twice with the exposure times, 1/8 second and 1 second. Then high sensitivity bands #1, #3 and #5 were extracted from 1 second exposure images and low sensitivity bands #2, #4, and #6 were extracted from 1/8 second exposure images.

Figure 3 shows linearly captured colour image. It is shown that objects under the box in the left size are almost uniformly black. Figure 4 shows a segmented image in which 15 kinds of band selection are rendered with different grey scales. White area and black area mean use of thee low sensitivity bands only and use of three high sensitivity bands only, respectively. Gray area corresponds to the other intermediate parts.

Spectral estimation and colour rendering were performed. For comparison, the spectral estimation from six low sensitivity bands and the spectral estimation from six high sensitivity bands were carried out. Rendered images are shown in Figure 5. For display of high dynamic range of luminance, luminance was compressed by the exponential transform with $\gamma = 1/2.2$. In Figure 5, (a) only light area in (a) and only dark area in (b) are well reproduced. It can be seen that the dark area in (a) is very noisy from the enlarged and brightened image as shown in the bottom row. On the other hand, in (c) both areas are well reproduced.

Figure 3: Original captured image (displayed linearly)

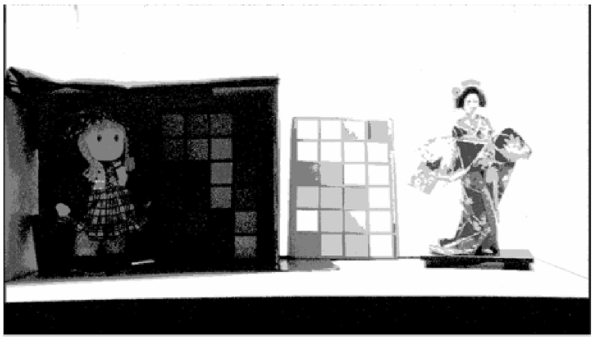
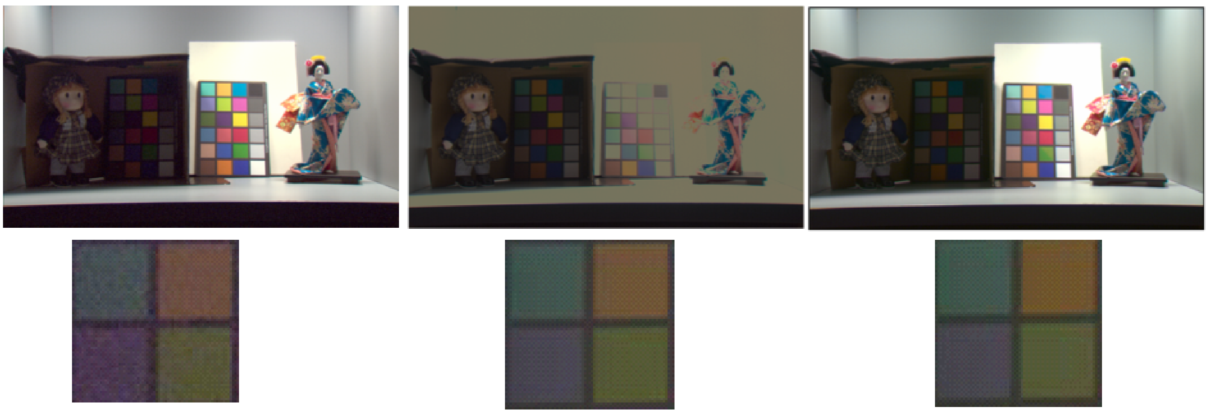


Figure 4: Segmented image with grey scales



(a) All low sensitivity (b) All high sensitivity (c) Proposed method

Figure 5: Rendered image after spectral estimation. Luminance is compressed by the exponential transform with $\gamma = 1/2.2$. Top row shows the full images and bottom row shows the top-left corner of the brightened and enlarged of the Macbeth chart in the box.

3.2 EVALUATION

As the image quality of reproduced images the accuracy of colour reproduction and the noise characteristics were evaluated quantitatively. As ground truth data, spectral radiances of all patches of Macbeth colour checkers in the dark and light position were measured by a spectrophotometer, PR650. The accuracy of colour reproduction was evaluated in terms of both spectral radiance and colorimetric values of 24 patches of the Macbeth colour checker. For the former, difference between the measured and estimated spectral radiance is calculated by root mean square error (RMSE). For he latter, the spectral radiance is once transformed to CIE-LAB values and then the colour difference is calculated. The results are listed in the top four rows in Table 2.

As expected, when all bands have low sensitivity, colour reproduction is good in the light are and bad in the dark area. On the contrary, when all bands have high sensitivity, colour reproduction is good in the dark area and bad in the light area. It is shown that the proposed method gives a reasonable compromise both in dark and light areas.

Noise characteristics were evaluated by the variance of luminance on each patch of the Macbeth colour checker in a dark area. Similar to the colour difference, the proposed method achieved good result similar to the case that all bands have high sensitivities.

Table 2: Quantitative evaluation of accuracy of colour reproduction and the noise characteristics of the reproduced image.

Criterion	Evaluation area	6 low sensitivities	6 high sensitivities	Proposed
RMSE in spectral estimation	Dark area	0.37	0.29	0.26
	Light area	0.07	0.56	0.16
Colour difference	Dark area	9.1	2.5	2.5
	Light area	2.9	35.4	7.7
Noise	Dark area	0.324	0.043	0.045

4. DISCUSSION AND CONCLUSIONS

In this paper, a method for expansion of dynamic range that uses a six-band camera consisting of three high sensitive bands and three low sensitive bands has been introduced. Experimental results demonstrated that the proposed method could provide a reasonable colour reproduction and noise characteristics. If the luminance range of the scene under the capturing is originally not so wide, the above mentioned setting of the sensitivities is not appropriate. Rather similar sensitivities are needed for good colour reproduction using six bands. By switching these two modes, the six-band camera would satisfy the wider requirement.

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