REAL-TIME HIGH DYNAMIC RANGE IMAGE GENERATION USING MULTIPLE CAMERAS

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ABSTRACT

In this paper, we propose a method for real time generation of high dynamic range images using multiple cameras. For precise estimation of the light environment, an image with a high dynamic range (HDR) is generally required. HDR image generation is also of interest for real-time applications such as augmented reality or augmented virtuality. Recently, an HDR camera with a sensitive sensor element (charge-coupled device) was developed. However, it is difficult to completely record a scene with a wide enough dynamic range using the camera because of the limited sensitivity of the sensor. A method for HDR image generation, which uses multiple images captured with different exposure times, has been proposed. However, using this approach, real-time processing is not possible because of the time required to capture multiple images. This paper proposes a method for real-time HDR image generation using multiple cameras, each of which is set to a different exposure time. These cameras can simultaneously capture multiple images with different exposure times, and these images are used to generate an HDR image in real time. We show results of an HDR image generation experiment by use of the proposed method in an environment where the cameras can observe both an outdoor and an indoor scene at the same time.

KEY WORDS
high dynamic range image, real time processing, multi-camera, exposure time

1 Introduction

In order to accurately acquire a real scene using a camera, it is necessary to capture an image of a high dynamic range (HDR). In particular, when a camera observes both an indoor and an outdoor scene at the same time or captures a light source directly, a dynamic range of more than 200 dB is generally required. Therefore, many methods for generating HDR images have been developed. However, most conventional methods are incapable of real-time processing because of the limitations of the equipment or high computational costs. In this paper, we propose a method for real-time generation of HDR images using multiple cameras.

The remainder of this paper is structured as follows: In Section 2, we briefly review related studies on HDR generation. In Section 3, we describe our real-time HDR image generation method that makes use of multiple cameras. In Section 4, some experimental results are presented. Finally, in Section 5, we present our conclusions.

2 Related work

One approach to generating HDR images is to use a camera with a sensitive receiving element. It is easy for a camera to capture a scene with HDR with a simple hardware configuration. However, it is difficult for the camera to record the entire dynamic range of a real scene because of the limited sensitivity of the sensor.

To acquire a wider dynamic range, some improvements to camera hardware have been proposed [1].In one method, receiving elements that are set to different exposure values are aligned on the accepting surface [2]. As a number of receiving elements are used to estimate a single pixel in this approach, spatial resolution is reduced. To overcome this problem, an approach that adaptively controls the exposure of each receiving element, so as not to reduce spatial resolution, was proposed [3, 4, 5]. This approach uses a camera combined with a device, which can attenuate the amount of light reaching the receiving element under independent control. As the device controls the incident radiance by changing attenuation based on the intensity of the light, the camera can operate at a suitable exposure. Use of this approach does not reduce spatial resolution because the exposure is controlled by a conventional approach. However, because this approach controls the exposure of the current frame based on the amount of light falling on the previous frame, it is difficult for the camera to determine the exposure when the light environment is changing drastically in time or space.

In another approach, an HDR image is generated from multiple images captured by a camera with various exposure times [6, 7, 8]. Because this approach uses multiple images captured using one camera with different exposure times, an HDR image with a wide and dense dynamic range can be constructed when many images are used [9]. The approach essentially imposes no limit on the width of the dynamic range, because this width depends on the number of images used to generate the HDR image. However, there is a tradeoff between the accuracy of an HDR image and generation time, because the HDR image is generated using many images captured with different exposure times. Therefore, the approach is not directly applicable to real-time processing.

Recently, attempts have been made to develop a real-time processing method for HDR image generation in order to apply it to real-time applications, such as augmented reality [10, 11, 12, 13].One such method determines the appropriate number of images and the exposure time of the current frame based on the dynamic range estimated from the light environment of the real world in the previous frame [14]. Although this method can speed up the capture of images, it does not provide real-time processing because only one camera is used to acquire the images.

In this paper, we propose a method for real-time HDR image generation using multiple cameras. The method employs the approach proposed in [6] and the images used for HDR generation are acquired simultaneously using multiple cameras. Because of the recent marked improvements in camera and computer hardware, it is now possible to process multiple images simultaneously using a single computer. In the proposed method, a different exposure time is set for each camera, and all images are captured simultaneously. Then, an HDR image is generated by combining these images in real time.

3 HDR Image generation using multiple cameras

This study employs an approach that generates an HDR image using multiple images captured with various exposure times. To achieve real-time processing for HDR generation, we use a multi-camera unit, which can capture multiple images and feed them into a computer in real time. By setting each camera to a different exposure time, images with different exposures can be acquired simultaneously. An HDR image can be generated in real time by combining these images. Because this method uses only images in the current frame, it can accurately generate an HDR image even if the light environment of the real world changes drastically.

This section is structured as follows: In Section 3.1, we introduce the multi-camera unit. In Section 3.2, we describe a method for camera calibration (preprocessing). In Section 3.4, a method for generating the HDR image is described.

3.1 Multi-camera unit

The multi-camera unit was used ProFusion (Viewplus). It can capture multiple images at the same time and can feed these images to a computer in real time. This camera unit consists of 25 cameras with a resolution of 640×480 pixels (VGA), and these cameras are arranged in a 5×5 matrix. They can capture color images and the images are fed into the computer via a PCI Express interface in real time. Because the individual cameras are arranged in a compact manner, the problem of parallax, i.e., displacement of a synthesized image as a result of difference in the positions of the projection centers of the camera, is avoided.In this multi-camera unit, the baseline distance between individual cameras is 12 mm, and the parallax of an object more than 5.2 m from the camera is less than one pixel in the captured image.

We set the parameters of exposure time and gamma correction of the camera, and the other parameters are fixed. As it takes a fixed amount of time to change the parameters of the camera because of its specification, we set these parameters when initializing the camera, and they are not updated during processing.

3.2 Camera calibration

It is necessary to calibrate the cameras in advance. In this method, it is necessary to estimate not only the intrinsic parameters but also the extrinsic ones during calibration, because the extrinsic parameters affect the displacement of individual images while generating the HDR image. Both intrinsic and extrinsic parameters of the camera are estimated by a conventional camera calibration method [15].According to the specification of the multi-camera unit, all the cameras are located on the same plane, the distance between two adjacent cameras being 12 mm, and the optical axes of all cameras are parallel and are vertical to the plane on which the cameras are located. However, as a camera usually includes error of camera alignment, both intrinsic and extrinsic parameters should be estimated. Using images of a checkerboard placed at a position where all the cameras can observe it, the extrinsic parameters, which represent the position and orientation of the camera, are obtained in the same coordinate system.

The orientation error of camera alignment was determined to be about 1 degree, and the displacement of image registration would result from this error. Therefore, the HDR image is composed of multiple images by using the estimated parameters. The camera calibration method can also estimate the positions of the cameras. However, because we assume that there is no object near the camera, their positions are not considered in our method. In other words, in this study, we assumed that the projection centers of all the cameras were at the same position.

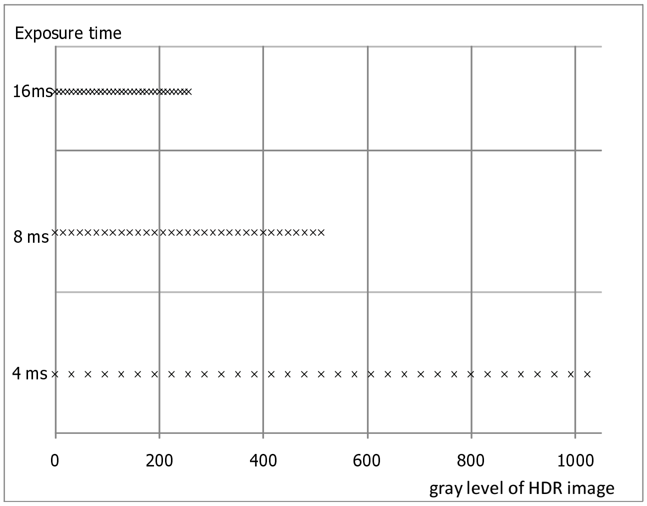

Figure 1. Relationship between dynamic range and exposure time.

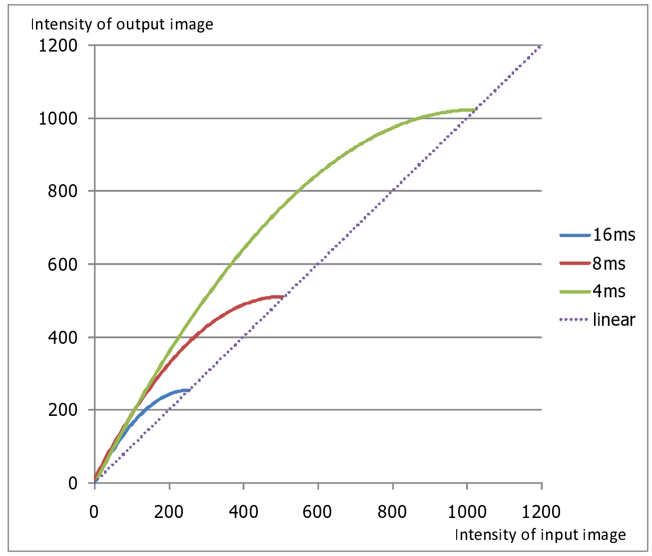

Figure 2. Effect of gamma correction

3.3 Real time HDR image generation

3.3.1 Overview of HDR image generation

In this subsection, we explain the method used to generate an HDR image from multiple images captured using cameras that are calibrated and set to different exposure times. First, we describe a method for estimating the intensity of the HDR image and for gamma correction, in order to decide the criteria for the selection of images used for HDR composition from input images. Next, a procedure for determining the HDR composition for each pixel is described.

3.3.2 Estimation of intensity

Figure 1 illustrates the relationship between exposure time of the camera and the dynamic range, which can be represented by the camera. The figure shows dynamic ranges for exposure times of 4 ms, 8 ms, and 16 ms. In the case of a half width of dynamic range, because the camera avoids saturation of pixel intensity, an image with two times the dynamic range can be acquired. However, because the dynamic range is quantized by a constant number of bits (usually 8 bits), the accuracy of quantization of an image whose exposure time is 4 ms is worse than that of an image whose exposure time is 8 ms. For this reason, an image with maximum possible exposure time should be used for HDR image composition. Let the intensity be $I_t(x,y)$ at position (x,y) in an input image whose exposure time is t; intensity $I_{HDR}(x,y)$ in the HDR image is then defined by Eq. (1)

$$I_{HDR}(x,y) = \frac{t_{max} \times t}{t_{min}} I_t(x,y), \tag{1}$$

where t_{min} and t_{max} are the minimum and maximum values, respectively, of the exposure times that can be set in the multi-camera unit.

3.3.3 Gamma correction

Figure 2 shows the intensity conversion of gamma correction. In this paper, gamma correction means enhancement of the low-intensity part of a captured image as well as intensity conversion of the usual display, as shown in Fig. 2. Let the intensity of input image at position (x,y) be $I_{in}(x,y)$; the intensity of the image after gamma correction is defined as the following equation:

$$I_{out}(x,y) = I_{max} \left(\frac{I_t(x,y)}{I_{max}} \right)^{\left(\frac{1}{\gamma}\right)}, \tag{2}$$

where I_{max} and γ are the maximum intensity value of the input image and the parameter of gamma correction, respectively. When γ is the higher value, the low-intensity part of the input image is enhanced more strongly. Gamma correction usually enhances a low-intensity part of an image to match the characteristics of human eyes. However, when only one camera is used, the accuracy of the high-intensity part of the image becomes low, because that part should be represented by fewer levels of color. The method using multiple cameras set to different exposure times can overcome this problem by covering the high-intensity part using an image, which is captured with a shorter exposure time. For example, when an input image captured with the shortest exposure time is converted by gamma correction, the low-intensity part, which can be converted efficiently, should be selected for HDR image generation. On the other hand, the bright part of the input image should not be used for HDR image generation; the intensity of that part is determined by an image captured with the next shorter exposure time.

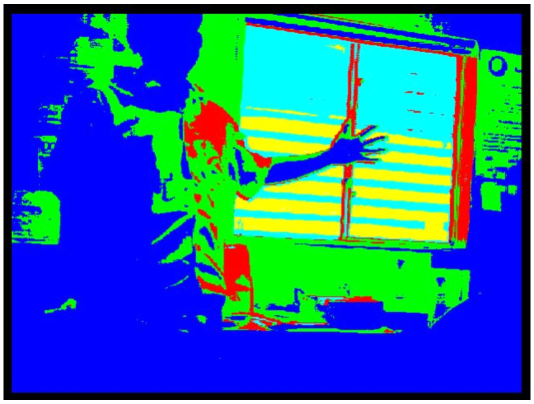

Figure 5. Image selected for HDR image generation.

3.3.4 Image composition by selecting image

Based on the above considerations, the following steps are required to determine the intensity of each pixel of an HDR image:

1. First, the system checks whether the intensity of the image captured with the longest exposure time satisfies a condition that judges whether the converted intensity is more accurate than the intensity before conversion by gamma correction. Because the function of gamma correction is a monotonically increasing function and convex upward, the intensity is more accurate than that before conversion when the gradient of the function of the gamma correction is more than unity. Therefore, the condition is defined by the following equation:

$$1 \leq \frac{I_{max}}{\gamma \times (I_{max})^{\frac{1}{r}}} I_t(x,y)^{\left(\frac{1}{\gamma}-1\right)} \quad (3)$$

   If the intensity does not satisfy the condition, the image with the next longest exposure time is used.

2. When the above condition is satisfied, the intensity of the HDR image is calculated using the following equation, which includes the gamma parameter and the exposure time:

$$I'_{HDR}(x,y) = \frac{I_{max} \times t_{max}}{t} \left(\frac{I_t(x,y)}{I_{max}} \right)^{\gamma} \quad (4)$$

   In the implementation, because I_{max} and γ are constant, the processing speed is increased by preparing a lookup table, which represents the relationship between the intensity values in advance.

The HDR image is generated by applying the above process to each pixel of the HDR image.

4 Experiment

We performed experiments to generate an HDR image in real time by the proposed method. In the experiment, a multi-camera unit was used, and nine cameras, which were arranged as a 3 × 3 matrix, of 25 cameras were used for HDR image generation. Because we can configure the range of exposure time from 1 ms to 33 ms, the exposure times of the cameras were set as 33, 29, 15, 21, 17, 13, 8, 5, and 1 ms, respectively, and the gamma correction parameter was set as 2. The experiments were performed using a laptop PC (CPU, Intel Core2 T7400, 2.16 GHz; Memory, 2.0 GB; Graphics card, Nvidia Quadro FX 3500M).

Input images captured by the nine cameras are shown in Figs. 3 and 6. In experimental environments, a multi-camera unit placed indoors can observe both an indoor and an outdoor scene at the same time. We can see that an image, which is captured with long exposure time, includes a saturated part, but a dark part of the real world, such as an indoor scene, can be observed clearly. We can confirm that an image captured with a short exposure time represents a bright part of the real world, such as outside a window, but the image does not contain information on dark parts of the real world. Figures 4 and 7 show the results of HDR image generation by the tone-mapping technique [16], which is used in image processing and computer graphics to map a set of colors to another set. This technique is generally use for approximating the appearance of a high dynamic range in a display with a more limited dynamic range. From these results, we can confirm that the proposed method can generate HDR images correctly. In the experiments, the frame rate of HDR generation was about 10 fps.

Figure 5 illustrates the number of cameras used for HDR image generation at each pixel. In other words, a part of same intensity in the image is calculated by a same input image. In this image, the color represents the number of camera of the multi-camera. The appropriate camera is selected at each pixel to generate the HDR image.

5 Conclusion

In this paper, we proposed a real-time HDR image generation method that uses multiple cameras set to various exposure times. By determining the image to be used for HDR image generation on the basis of the current captured image, the proposed method can generate an HDR image even if the light environment of the real world changes drastically. Results of HDR image generation obtained in an experiment confirmed the feasibility of the proposed method. The frame rate of the method is 10 fps.

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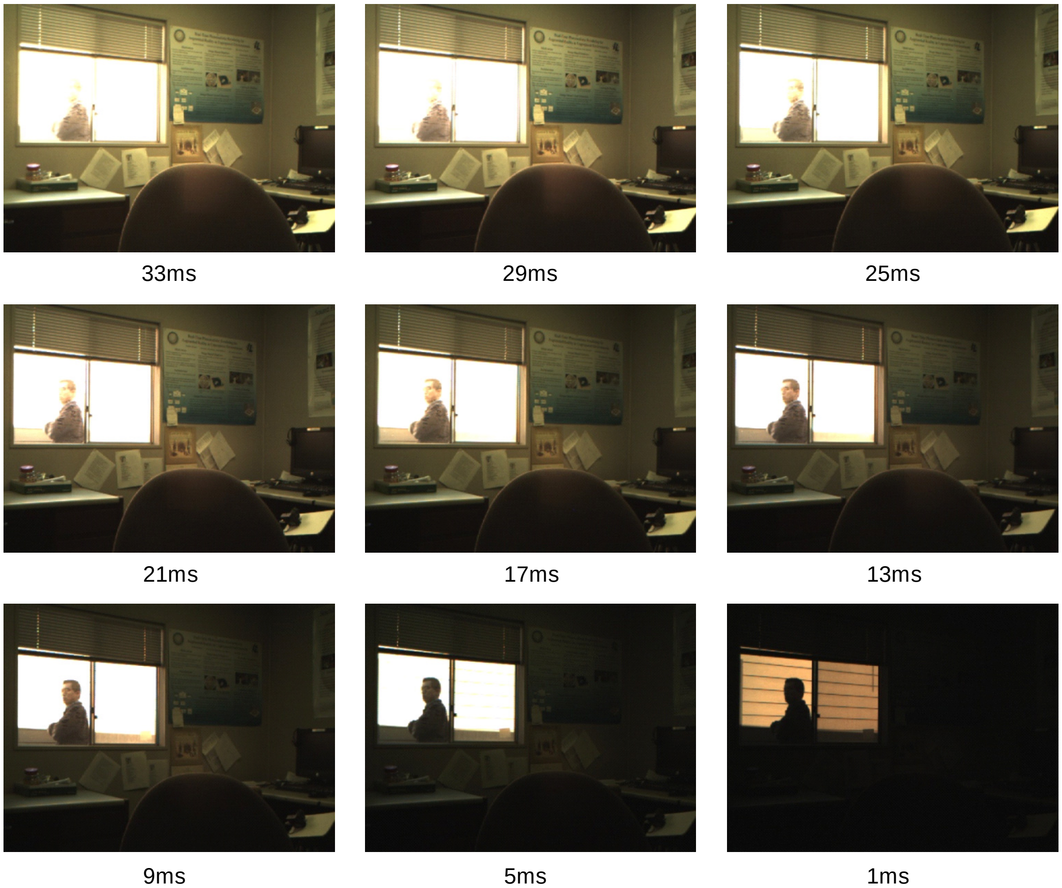

Figure 3. Input images of room scene

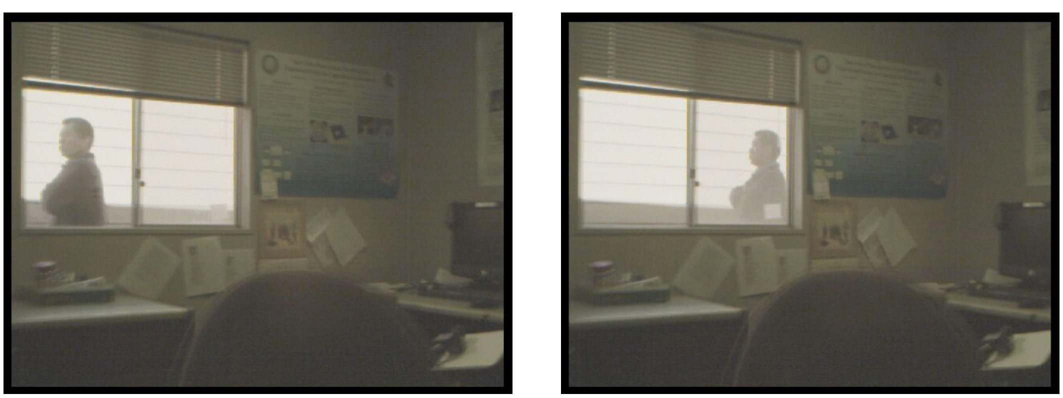

Figure 4. Composed HDR images of a room scene

Figure 6. input images of a hallway scene

Figure 7. Composed HDR images of a hallway scene