High Dynamic Range Imaging Using Coded Electronic Shutter*

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POSTECH

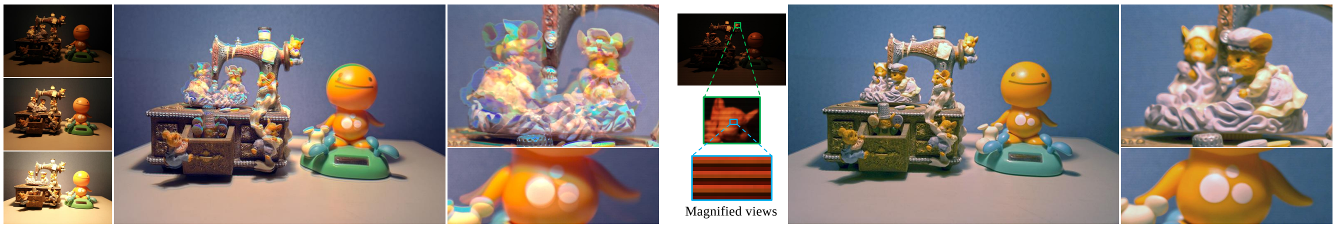

Figure 1: *Multiple image based HDR imaging vs. our single-shot HDR imaging for moving objects. The input image of our method was captured using a prototype camera equipped with a coded electronic shutter. Both results are equally tone-compressed for visualization. Our method is robust to motions (e.g., object motions and camera shakes) and does not suffer from rolling shutter artifacts such as skew or wobble.*

1 Introduction

High dynamic range (HDR) imaging aims to increase the dynamic range of imaging devices, capturing better representations of target scenes. Since the seminal work of Debevec and Malik [1997], tremendous progress has been achieved utilizing multiple images of different exposures that provide complementary brightness information of a scene. However, their application is limited to static scenes with no motions during the sequential capture of images, because changes between images can cause undesirable artifacts such as ghosts. Special imaging devices such as exposure-filtering masks [Nayar and Mitsunaga 2000] could reduce motion artifacts, but manufacturing costs have limited their practicality.

In this paper, we propose a novel HDR imaging method using a coded electronic shutter (CES) that allows simultaneous capture of spatially varying exposures in a single image. Recently, electronic shutter has been widely adopted in digital cameras, where the mechanical front curtain shutter (Fig. 2a) is replaced by the electronic reset signal. On top of the electronic shutter, CES can be easily implemented by triggering row-wise different reset signals (Fig. 2b). As the speed of row-reset is comparable to that of the physical shutter, electronic shutters do not suffer from rolling shutter artifacts such as skew or wobble. The major benefit of using CES in HDR imaging is significant reduction of ghosts due to the concurrent capture of multiple exposures. Using a single image of multiple exposures acquired by CES, we extend its dynamic range without extracting sub-images of each exposure while preventing jaggy artifacts and preserving fine details. We adapt several image filtering algorithms based on variational formulations to suppress possible artifacts. As shown in Fig. 1, our method can robustly produce a high quality HDR image without artifacts.

2 Algorithms

The key idea of our approach is exploiting the multiple exposure pixels obtained using CES to extend the dynamic range. Our timing function for HDR imaging consists of two exposure values (Fig. 2b), and accordingly we obtain $I = \{I_L, I_S\}$ from CES where I_L and I_S represent long- and short-exposure pixels, respectively.

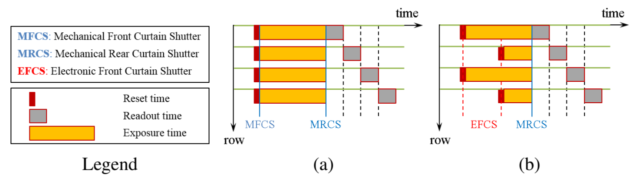

Figure 2: *Conceptual timing charts for camera shutter functions. (a) Two-curtain focal-plane shutter and (b) Coded electronic shutter.*

Extracting two subimages I_S and I_L can lose fine-details, so we directly manipulate I itself without extracting the subimages.

Since I_S and I_L have different exposure values, we first need to compensate their different exposures. To do this, we perform photometric calibration using the response curve of an image sensor, where the curve can be precomputed. As a result of calibrating the short-exposure to become long-exposure, we obtain $\{I_L, I_{S\to L}\}$. Since $I_{S\to L}$ may contain noise due to the inaccuracy of photometric calibration, we further remove the calibration error using anisotropic diffusion, based on statistical analysis of the error. Then, as I_L and $I_{S\to L}$ are expected to have the same long exposure value, we restore over-/under-exposed areas using the complementary information of I_L and $I_{S\to L}$. For example, the over-exposed pixels of I_L are recovered using nearby pixels of $I_{S\to L}$. We propose a novel bilateral filter for this step, which considers edge direction and the state of pixels (i.e., under-/well-/over-exposed). Finally, since I_L may contain longer motions than $I_{S\to L}$ when a dynamic scene is caputred, we further surpress the potential motion artifacts using mean curvature flow like diffusion algorithm derived from a variational formulation [Lenzen and Scherzer 2011]. As shown in Fig. 1, our method is robust to motions and produces high quality HDR images.

References

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