Multi-spectral Flash Imaging under Low-light Condition using Optimization with Weight Map

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Keywords: Multi-spectral Flash, Weight Map, Computational Photography.

Abstract: Long exposure shot and flash lights are generally used to acquire images under low-light environments. However, flash lights often induce color distortion, red-eye effect, and they can disturb the subject. The other hand, long-exposure shots are prone to motion-blur due to camera shake or subject-motion. Recently, multi-spectral flash imaging has been introduced to overcome the limitations of traditional low-light photography. Multi-spectral flash imaging is performed by combining the invisible and visible spectrum information. However, common multi spectral flash approaches induce color distortion due to the lower accuracy of the invisible spectrum image. In this paper, we propose a multi-spectral flash imaging algorithm using optimization with weight map in order to improve color accuracy and brightness of image. The UV/IR and visible spectrum images are firstly captured, respectively. Then, to compensate luminance value under low light condition, tone reproduction is performed by using adaptive curve due to image features that is obtained by Naka-Rushton formula. Next, to discriminate uniform regions from detail regions, weight map is generated by using Canny operator. Finally, the optimization object function takes into account the output likelihood with respect to the visible light image, the sparsity of image gradients as well as the spectral constraints for the IR-red channels and UV-blue channels. The performance of the proposed method has been subjectively evaluated using z-score, and we also show that output images have improved color accuracy and lower noise with respect to other methods.

1 INTRODUCTION

Cameras generally produce images by acquiring light in a controlled fashion: camera shutter speed, aperture, and flash all play important roles in the acquisition process. In particular, the most common solutions for low-light photography are either the use of flash lights or the use of long exposure times.

On one hand, flashes often introduce undesired artifacts or effects, such as red-eyes, false shadows, high intensity specular reflections and changes in the color of ambient light. Furthermore, flash lights may dazzle the subjects because of their impulsive nature and high intensity. A number of methods have been proposed to reduce the artifacts produced by the use of flash lights, for example, highlight and reflection removal by gradient coherency (Agrawal et al., 2005). On the other hand, long-exposures are particularly difficult because of possible subject or camera motion, which will produce image blur. While blur due to subject motion is a harder problem, blur resulting from camera shake has been approached by various methods, such as new imaging systems that introduce panchromatic pixels as the image prior (Wang, 2012) or the estimation of motion blur, e.g. by solving a maximum a-posteriori problem (Fergus et al., 2006; Jiaya, 2007).

Research on the acquisition of high-quality images in low-light environments is very active topic and a number of solutions have been proposed, the general trend being the acquisition of extended data (multi-spectral images or multiple exposures). One of such approach is based on flash/no-flash image couples and bilateral filtering: image noise in the no-flash image is reduced via bilateral filtering and detail is transferred from the flash image using joint-bilateral filtering (Petschnigg et al., 2004; Eisemann et al., 2004). However, this method still requires the use of a flash gun, which may result in subject discomfort. Another approach requires the acquisition of one image in the visible spectrum and one in the UV/IR spectrum. The acquisition is possible owing to the extended sensitivity of modern digital camera sensors and the use of an invisible

Choi B., Kim D., Kyung W. and Ha Y..
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DOI: 10.5220/0004657500330039
In *Proceedings of the 9th International Conference on Computer Vision Theory and Applications* (VISAPP-2014), pages 33-39
ISBN: 978-989-758-003-1

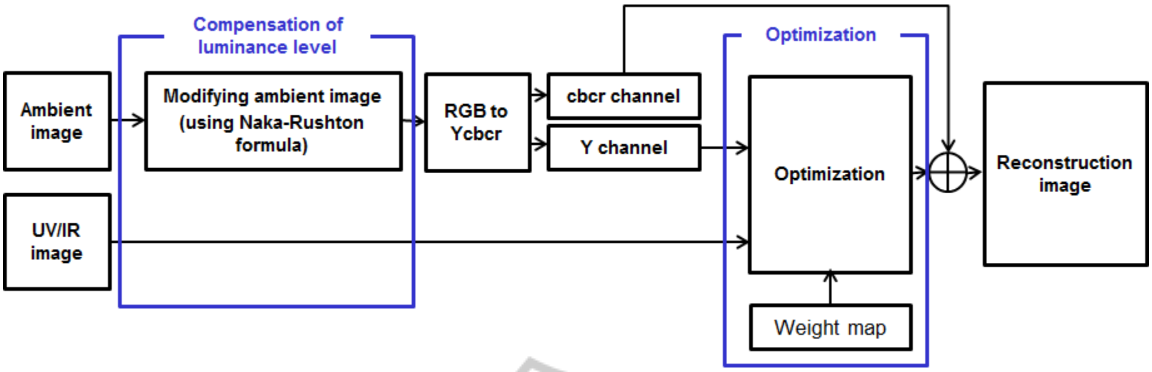


Figure 1: Flow chart of the proposed method.

light flash gun. The visible spectrum image then becomes the source of color information, while the UV/IR spectrum image is used to extract details. Krishnan and Fergus proposed the use of UV, IR and visible spectrum data together with iterative re-weighted least squares (IRWLS) optimization(D. Krishnan and R. Fergus, 2009). Later, Zhuo et al. made use of weighted least squares (WLS) optimization to simultaneously perform visible spectrum image denoising and IR spectrum image detail transfer (Zhuo et al., 2010). These approaches still produce output images affected by color distortion and artifacts since they assume that UV/IR spectrum images are noiseless image, yet noise is actually present in the UV/IR spectrum image. The purpose of the optimization was to minimize difference of details between reconstruction image and UV/IR image. However, the gradient values of noises are also treated as detail information in optimization process. For this reason, optimization achieved detail enhancement and denoising in visible spectrum image. At the same time, color distortion and artifacts are produced by the UV/IR spectrum image`s noise in uniform region.

In this paper, we suggest the acquisition of a high quality image in low-light condition using multi-spectral flash imaging. To for compensate low luminance values under low-light conditions, adaptive tone reproduction is performed by using Naka-Rushton formula, then, a weight map representing the feature of the scene is calculated by applying the Canny operator to Y channel of the UV/IR image. The weight map is thus used to discriminate uniform and detail regions during the optimization process. Uniform regions are computed with decreased detail term influence and applied bilateral filter whereas detail region are computed with increased detail term contribution. Therefore, the proposed method can achieve noise reduction and improved color accuracy with respect to previous works.

2 MULTI-SPECTRAL FLASH IMAGING BASED ON WEIGHT MAP

In order to obtain a high-quality image in low-light conditions by using the multi-spectral flash imaging, there is need to compensate for the low-luminance values, enhance the detail and reduce noise. Because captured image without flash light are generally dark and UV/IR image have a lot of details. The process of multi-spectral imaging based on weight map is illustrated in Fig. 1. Firstly, to compensate luminance value, Naka-Rushton formula is applied to dark and bright region of visible spectrum image. Next, to enhance the detail information and reduce the noise, Y channel of visible spectrum image is optimized by using detail information of UV/IR flash and visible spectrum images. To optimize a pair of images, visible and UV/IR flash image are converted to YCbCr color space and the optimization method uses only Y channel. In optimization process, we applied weight map as discriminate between uniform region and edge region for reducing UV/IR flash image`s noise of uniform region and it is generated by using by multi-scale Canny edge operator. Finally, reconstruction image is combined by visible spectrum image`s Cb and Cr channels and optimized Y channel.

2.1 Acquisition of Visible and UV/IR Spectrum Image

Multi-spectral flash imaging uses visible and UV/IR spectrum image pair. A visible and UV/IR spectrum image pair captures the scene at 5 difference

(a) (b)

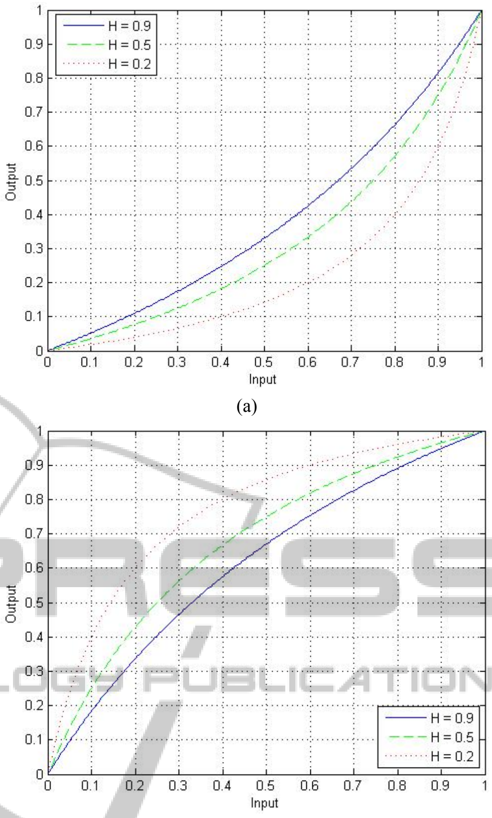
Figure 2: Multi-spectral images; (a) visible spectrum image. (b) UV/IR spectrum image.

spectrum bands that UV (370~400nm), B, G, R, and IR (700~800nm). However, commercially available digital cameras obtain images in the visible spectrum only. To acquire both the UV/IR and visible spectrum, we modified a common digital camera system (Samsung NX-100) as follows. First, IR-cut filter in front of CCD sensor was removed for acquiring IR spectrum band. And, IR-cut filter(~800nm) was attached on camera lens to avoid excessive IR spectrum energy acquisition. Next, the UV absorb coating of Xenon flash lamp was removed to allow UV spectrum projection and acquisition. Finally, a visible light cut filter was attached in front of the flash light to reduce discomfort. The visible and UV/IR flash image are captured by the modified camera, as shown in Fig. 2. UV/IR flash images are noise free and contain plentiful detail information from the scene. However, UV/IR flash images do not have color information, as shown in Fig. 2(a). On the contrary to UV/IR image, no-flash image contains color information and noise in Fig. 2(b).

2.2 Compensation of Low Luminance Value in Visible Spectrum Image

The visible spectrum image has low-luminance levels due to low ambient lighting and short exposure time. In order to improve the quality of the image we need to compensate for the low luminance values. While, gamma correction can be used to compensate for such problem, it causes the appearance of noise in dark regions and saturated pixels in bright regions. Thus we compress the luminance data in a different way, using the Naka-Rushton formula (Naka and Rushton, 1966). The Naka-Rushton formula can be represented as follows..

$$I_c(i,j) = \frac{I_v(i,j)}{I_v(i,j)+H}\left(\max(I_v(i,j)+H\right) \qquad (1)$$



(a)

(b)

Figure 3: Naka-Rushton curve and inverse Naka-Rushoton curve according to parameter *H*: (a) inverse Naka-Rushton curve apply to dark region, (b) Naka-Rushton curve apply to bright region.

where, $I_v(i,j)$ and $\max(I_v(i,j))$ are the pixel value of visible spectrum image and maximum pixel value of visible spectrum image, respectively. The parameter H controls the function`s slope. $\max(I_v(i,j))+H$ is normalized to make output I_c in the range of [0,1].

To compress dark current noise in dark region and compensate pixel value in bright region, Naka-Rushton curve or inverse Naka-Rushton curve is applied according to threshold T as follows.

$$I_c(i,j) = \begin{cases} 1 - \dfrac{1-I_v(i,j)}{(1-I_v(i,j))+H}\left[(1-T)+H\right] & 0 < I_v(i,j) \le T \\ \dfrac{I_v(i,j)}{I_v(i,j)+H}(T-H) & T < I_v(i,j) \le 1 \end{cases} \qquad (2)$$

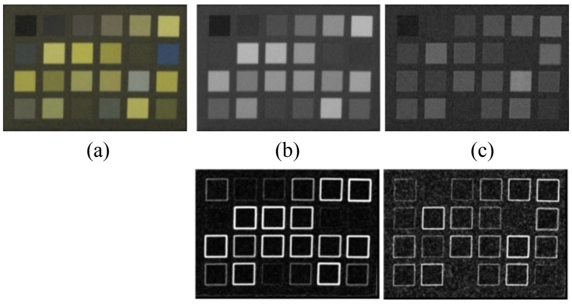
where, T is the threshold used to divide dark region and bright region..

The Naka-Rushton and inverse Naka-Rushton curve in Equation (2) are as shown in Fig. 3. The adaptive curve due to image features is applied to image by using Parameter H and threshold T. Therefore, visible spectrum with compensated luminance is acquired.

2.3 Optimization of Multi-Spectral Flash Image using Weight Map

The previous multi-spectral flash imaging is an efficient technique for acquiring images in low-light environments without visible flash and long-exposure time (D. Krishnan and R. Fergus, 2009). However, this method introduces color distortion and artifacts. While it is assumed that UV/IR flash images are noiseless, this isn't true as seen in Fig. 4. The purpose of the optimization was to minimize difference of details between reconstruction image and UV/IR flash image. However, as seen in Fig. 4 noise is existed on UV/IR flash images. This gradient value of noises was also computed as a detail information in the optimization process. For this reason, optimization achieved detail enhancement and denoising in no-flash image whereas color changes and artifact were produced by the UV/IR spectrum image`s noise in uniform regions.

In this paper, For enhancing detail information and denoising, optimization process is performed by using luminance enhanced visible spectrum image and UV/IR flash image, as follows. First, visible spectrum image is converted into YCbCr color space for calculating the luminance and color channels, separately. Then, luminance channel is applied to optimization process for reproducing the detail of image. In optimization process, weight map is applied to a pair of images of visible and invisible image for enhancing detail information and reducing the artifacts in uniform region.


(a) (b) (c)

(d) (e)

Figure 4: Problem of UV/IR spectrum image use to detail enhancement and denoising; (a) UV/IR flash image, (b) R channel with UV/IR flash image, (c) B channel with UV/IR image, (d) edge map of (b), (e) edge map of (c).

2.3.1 Weight Map Construction

The previous method was solving optimization by pixel-by-pixels. To improve the previous method, we added feature information in optimization process. In other words, we build weight map for discriminate between uniform region and edge region in the scene. For constructing weight map containing detail of the scene and reducing false detail(noise of uniform region), we apply gaussian filtering for different four sigma value. The flow chart of constructing weight map is shown in Fig. 5.

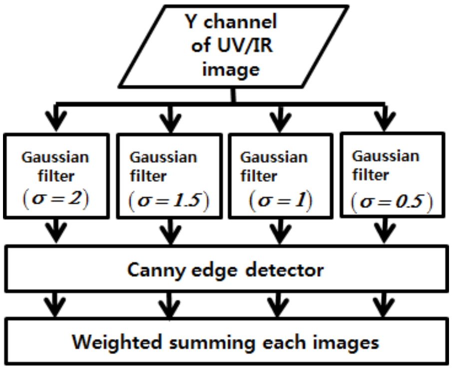


Figure 5: The Flowchart of constructing weight map.

In this work, we use luminance channel of UV/IR spectrum image`s. RGB color space is translated to YCbCr color space as follows.

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.2126 & 0.7152 & 0.0722 \\ -0.1146 & -0.3854 & 0.5 \\ 0.5 & -0.4542 & -0.0458 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{3}$$

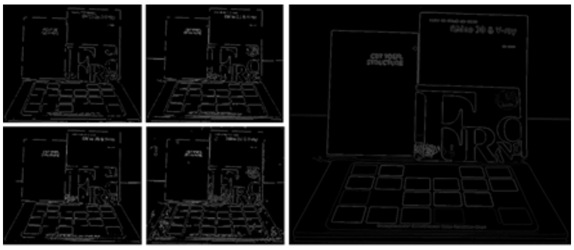

(a) (b)

Figure 6: Proposed combined weight map; (a) applying different gaussian scale smoothing(σ=2, 1.5, 1.0, 0.5) in Y channel with UV/IR flash image, (b) combined weight map.

To detect robust feature, a combined weight map was proposed. In this work, our goals are to improve the detail representation performance and reduce false details by combining four weight maps, Gaussian applied different scale for smoothing, and then we apply them to canny edge detection (Canny, 1986). Representing combined weight map M in eq. (4).

$$M(x,y) = \sum_{j=1}^{J} w_j \cdot E_j(x,y) \tag{4}$$

where,

$$E_j(x,y) = \begin{cases} I_{iY}(x,y), & E_j(x,y) > 0 \\ 0, & otherwise \end{cases} \tag{5}$$

where E_j is jth weight map. Here, w_j denotes the weight with the sigma values of gaussian blur filtering, and $I_{iY}(x,y)$ denotes the intensity value of Y channel of the UV/IR flash image. The combined weight map is shown in Fig. 6.

2.3.2 Multi-Spectral Flash Image Reconstruction based on Weight Map

We apply weight map in order to complement pixel-by-pixel optimization method with the previous multi-spectral flash imaging. In other words, weight map discriminates weighting in optimization process with uniform region and detail region. The weight map is used to decrease the weight of detail term in uniform region and to increase the weight of detail term in detail region. Accordingly, detail region is enhanced because detail information of UV/IR flash image is mainly applied to detail region of reconstruction image and information of visible spectrum image is mainly applied to uniform region of reconstruction image.

Therefore, reconstruction image is obtained by solving the object function of the optimization as follows.

$$\arg\min_{R_Y} \sum_p \begin{bmatrix} \mu\left(R_Y(p) - I_{cY}(p)\right)^2 + \kappa\left|\left(M\cdot\nabla R_Y(p)\right)\right|^\alpha + \\ \left|\left(M\cdot\nabla R_Y(p) - \nabla I_{i\_IR}(p)\right)\right|^\alpha + \\ \left|\left(M\cdot\nabla R_Y(p) - \nabla I_{i\_UV}(p)\right)\right|^\alpha \end{bmatrix} \tag{6}$$

where M denotes proposed weight map and I_{cY}, I_{i_IR} and I_{i_UV} are Y channel of visible spectrum image, R channel of UV/IR flash image, and B channel of UV/IR flash image, respectively. And μ, κ and α are parameters for optimization. The object function is solved by using iterative re-weight least square (IRWLS) (Krishnan and Fergus, 2009). Implementations of optimization for only Y channels with 5 iteration per channel. Weight of each term calculates by eq. (4) and (5).

$$\arg\min\left|R_Y - \nabla I_i\right|^\alpha = \arg\min\left|\left(M\cdot W_i\right)\cdot R_Y - I_i\right| \tag{7}$$

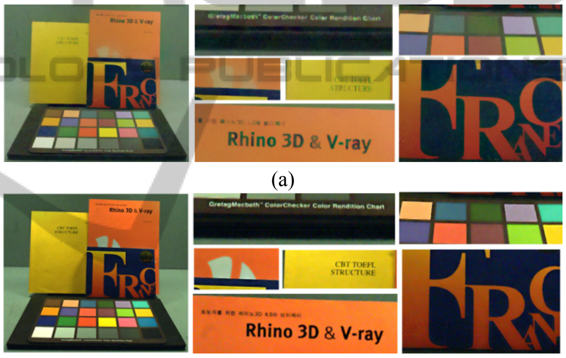
$$W_i = \left|R_{i-1} - F\right|^{\alpha-2} \tag{8}$$

where W_i denotes i th iterative weight for solving optimization. namely, according to eq. (8), calculating weight each iterations with weight map. After optimization of Y channel, reconstruction of Y channel is combined with CbCr channel of visible spectrum image.

3 EXPERIMENTS AND RESULTS

3.1 Experimental Environments and Results

To acquire multi-spectral flash image, we used a modified Samsung NX-100 camera (as described in Sec. 2.1). We acquired the UV/IR and visible spectrum images under 90 lux of illumination. Fig. 7 and 8 represented the resulting images of the proposed method and D. Krishnan and R. Fergus`s method. The parameters used are H=0.97 and T =0.3. As seen Fig. 7 and 8, the proposed method reduces color artifacts and distortion more than the previous method, in particular color distortion in uniform regions. The performance of the proposed method has been subjectively evaluated by using z-score (Morovic, 2008). We tested color rendition, noise presence, and personal preference for 7 images.


(a)

(b)

Figure 7: Resulting images; (a) Krishnan and Fergus`s method (b) proposed method.

Table 1: z-score of color preference between D. Krishnan and R. Fergus`s method and proposed method.

	Previous method	Proposed method
Book1	-1.644853	1.644853
Book2	-1.644853	1.644853
Book3	-0.38532	0.38532
Person1	-0.125661	0.125661
Person2	-0.841621	0.841621
Dolls	-0.38532	0.38532
Bowls	-6	6

Table 2: z-score of comparing noise between D. Krishnan and R. Fergus`s method and proposed method.

	Previous method	Proposed method
Book1	-1.644853	1.644853
Book2	-1.036433	1.036433
Book3	-1.281551	-1.281551
Person1	0.125661	-0.125661
Person2	-0.125661	0.125661
Dolls	-0.67499	0.67499
Bowls	0	0

(a)

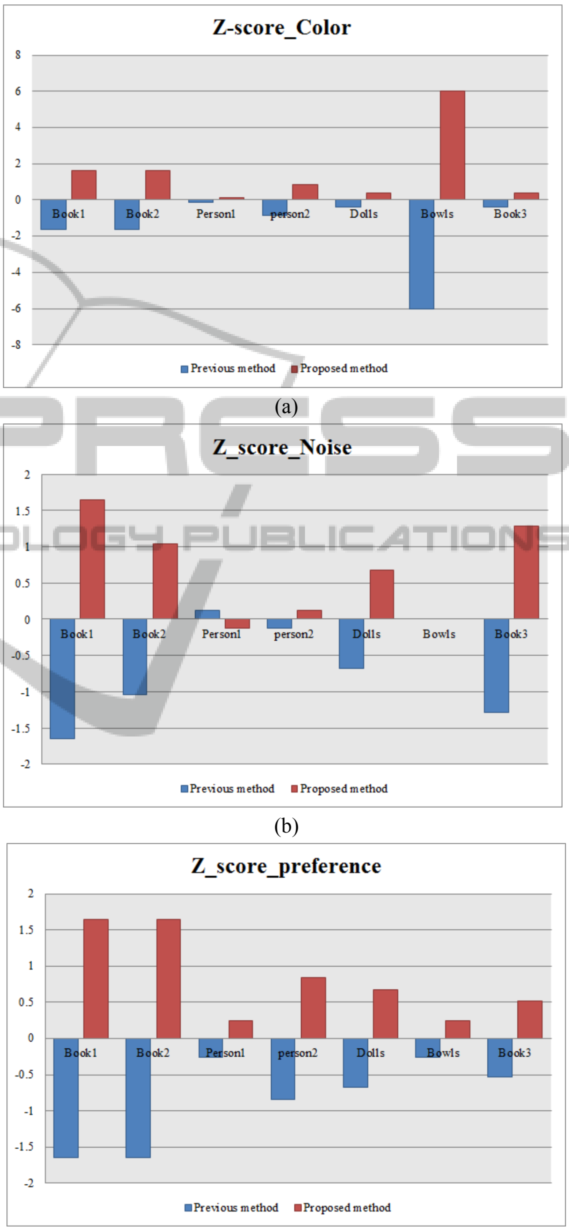
(b)

Figure 8: Resulting images; (a) Krishnan and Fergus`s method (b) proposed method.

Table 3: z-score of personal preference between D. Krishnan and R. Fergus`s method and proposed method.

	Previous method	Proposed method
Book1	-1.644853	1.644853
Book2	-1.644853	1.644853
Book3	-0.524401	0.524401
Person1	-0.253347	0.253347
Person2	-0.841621	0.841621
Dolls	-0.67499	0.67499
Bowls	-0.253347	0.253347

The investigation is based on 30 observers with 20 ordinary person and 10 image processing professionals. Experimental results are represented in Tables 1, 2 and 3 and Fig. 9. The z-score for the proposed method are generally higher than D. Krishnan and R. Fergus`s method.



(a)

(b)

(c)

Figure 9: comparison of z-score of color, noise and personal preference between D. Krishnan and R. Fergus`s method and proposed method; (a) evaluation of color accuracy, (b) evaluation of noise reduction, (c) personal preference of resulting image.

4 CONCLUSIONS

Multi-spectral flash images are a combination of UV/IR and visible spectrum information. This paper proposes a multi-spectral flash imaging algorithm based on an optimization problem and a combined weight map to enhance detail and reduce noise and artifacts. The Naka-Rushton curve is used to compensate for the low luminance values in visible spectrum image. Also, to compress dark current noise and avoid saturation, the Naka-Rushton curve is applied adaptively to dark and bright regions. The optimization process is enhanced by using a weight map that decreases the weight of false details in uniform regions. Experimental results showed improvements in color accuracy and a lower presence of artifacts when compared to previous methods.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Education, Science and Technology (MEST) (No. NRF-2013R1A2A2A010 16105)

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