# GEOMETRICAL TRANSFORMATION-BASED GHOST ARTIFACTS REMOVING FOR HIGH DYNAMIC RANGE IMAGE

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## ABSTRACT

In this paper, we propose a ghost artifacts removing algorithm for obtaining artifact-free high dynamic range (HDR) images in the presence of camera movement. Existing HDR methods work on condition that there is no camera movement when acquiring multiple low dynamic range (LDR) images. For overcoming such unrealistic restriction, the proposed algorithm first specifies the target and the source images in the set of acquired LDR images, and then the source image is transformed to fit the target image by estimating translation and rotation components in the affine matrix. Therefore, the proposed algorithm can reconstruct the HDR image without ghost artifacts because camera movement is completely removed in transformed images. Experimental results show that the proposed algorithm successfully removes ghost artifacts. For this reason, the proposed algorithm can extend application areas of HDR imaging to various mobile imaging devices, such as a handheld camcorder and a mobile phone camera.

***Index Terms—*** HDR, High dynamic range image, Image registration, Motion compensation

## 1. INTRODUCTION

High dynamic range (HDR) imaging has been an active topic in the field of computer vision and graphics in the last decade. Combining differently exposed low dynamic range (LDR) images of the same scene has been the most popular approach to generate an HDR image [1,2]. In spite of promising results of existing HDR methods, the requirement of static acquisition limits their application into the studio-level ideal environment. In other words, these methods cannot avoid ghost artifacts in the presence of camera movement. However, modern mobile imaging devices require the HDR function without ghost artifacts from dynamic acquisition.

Our work is related to the recent research combining multiple images of different exposure to produce sharp and clean image and image registration. Debevec introduced the classic method of combining multiple photos to create HDR image, assuming a fixed camera and a static scene [1]. Subsequent works generalize it to varying viewpoints [3,4]. Lu recently combined deblur and HDR creation, but their method is limited to spatially-invariant kernel [5]. In order to produce a sharp and clean HDR image, the proposed algorithm registers differently exposed LDR images using elastic registration (ER) algorithm to minimize geometric error between LDR images [6].

The key advantage of the proposed algorithm is the ability to generate HDR images without ghost artifacts in presence of camera movement. For this reason the proposed algorithm can be applied to various mobile imaging devices, such as handheld camera, mobile phone camera.

The rest of the paper is organized as follow. We present ER algorithm to register LDR image in section 2. In section 3, we show some experimental results to confirm the validity of our work with comparison to the Debevec's method [1] and the existing commercial products [7,8], and section 4 concludes the paper.

## 2. LOW DYNAMIC RANGE IMAGE REGISTRATION USING ELASTIC REGISTRATION

In order to combine the multiple LDR images without ghost artifacts, we need an image registration algorithm. Periaswamy proposed ER algorithm that geometrically register a source image to a target image using the affine matrix [6].

For efficient registration of LDR images, we assume the camera movement, which consists of translation and rotation. Therefore, affine matrix of ER algorithm is contained translation and rotation component.

Denote $f(x, y, t)$ and $f(\hat{x}, \hat{y}, t-1)$ as the source LDR images and target LDR image respectively. We begin assuming the image intensities between images are conserved and that the motion between LDR images can be modeled by an affine transform as:

$$f(x, y, t) = f(m_1 x + m_2 y + m_5, m_3 x + m_4 y + m_6, t-1), \quad (1)$$

where $m_1$, $m_2$, $m_3$, and $m_4$ are the linear affine parameters and $m_5$ and $m_6$ are the translation parameters. In order to estimate these parameters, we define the following quadratic error function to be minimized as:

$$E(\vec{m}) = \sum_{x,y\in\Omega} \begin{bmatrix} f(x,y,t) \\ -f(m_1x+m_2y+m_5, m_3x+m_4y+m_6, t-1) \end{bmatrix}^2, \quad (2)$$

where $\vec{m} = (m_1 \cdots m_6)^T$, $\Omega$ denotes a small spatial neighborhood. Since this error function is nonlinear in its unknowns, it cannot be minimized analytically. To simplify the minimization, we approximate this error functions using a first order truncated Taylor series expansion as:

$$E(\vec{m}) \approx \sum_{x,y\in\Omega} \left( f(x,y,t) - \begin{bmatrix} f(x,y,t) + (m_1x+m_2y+m_5-x) f_x(x,y,t) \\ +(m_3x+m_4y+m_6-y) f_y(x,y,t) - f_t(x,y,t) \end{bmatrix} \right)^2, \quad (3)$$

where $f_x$ and $f_y$ are spatial derivatives of $f$, and $f_t$ is the temporal derivatives of $f$. Based on Taylor series expansion, the error function is further reduced as:

$$E(\vec{m}) = \sum_{x,y\in\Omega} \left[ k - \vec{c}^T \vec{m} \right]^2, \quad (4)$$

where the scalar $k$ and $\vec{c}$ are given as:

$$k = f_t + xf_x + yf_y, \; \vec{c} = \left( xf_x \;\; yf_x \;\; xf_y \;\; yf_y \;\; f_x \;\; f_y \right)^T. \quad (5)$$

This error function can now be minimized analytically by differentiating with respect to the unknown as:

$$\frac{dE(\vec{m})}{d\vec{m}} = \sum_{x,y\in\Omega} -2\vec{c} \left[ k - \vec{c}^T \vec{m} \right]. \quad (6)$$

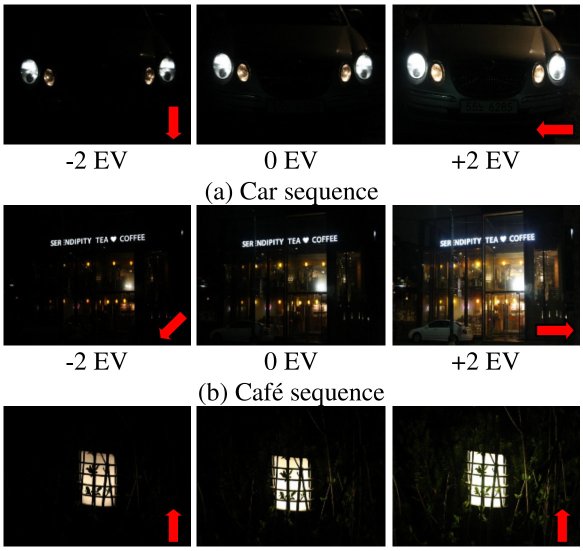
Setting this result equal to zero and solving for $\vec{m}$ yields as:

$$\vec{m} = \left[ \sum_{x,y\in\Omega} \vec{c}\vec{c}^T \right]^{-1} \left[ \sum_{x,y\in\Omega} \vec{c}k \right]. \quad (7)$$

We can estimate $\vec{m}$ using above equation. A more accurate estimation of the actual error function can be performed by using the Newton-Raphson type iteration. More specifically, at each iteration, the estimated transformation is applied to the source LDR images and a new transformation is estimated between the newly translated and rotated source and target LDR image. Also, the required spatial/temporal derivatives have finite support, which restricts the amount of motion that can be estimate. A coarse-to-fine approach is adopted in order to content with larger motion. A Gaussian pyramid is built for both source and target LDR images. The affine parameters are used to translate and rotate the source LDR image in the next level of the pyramid.

## 3. EXPERIMENTAL RESULTS

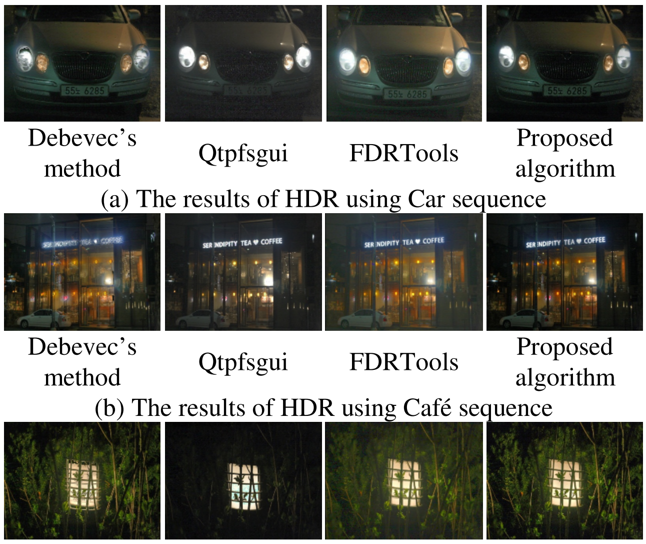
We conducted experiments using a variety of real images to verify the effectiveness of the proposed method. The images are captured by Canon EOS-5D Mark II. For the simplicity of processing, all image size are reduced to $640 \times 480$. Our experimental results are compared with Debevec's method [1], and current commercial products [7,8]: FDRTools and Qtpfsgui.



-2 EV 0 EV +2 EV
(a) Car sequence
-2 EV 0 EV +2 EV
(b) Café sequence
-2 EV 0 EV +2 EV
(c) Lamp sequence

Fig. 1. The test sequences of LDR images with different exposure values.

The test sequences with different exposure values (EVs) are shown in Fig. 1. Test sequences are acquired in night and in the presence of camera movement. The target LDR image is 0 EV image in each sequence and red arrow represents the direction of camera movement.



Debevec's method | Qtpfsgui | FDRTools | Proposed algorithm
(a) The results of HDR using Car sequence
Debevec's method | Qtpfsgui | FDRTools | Proposed algorithm
(b) The results of HDR using Café sequence
Debevec's method | Qtpfsgui | FDRTools | Proposed algorithm
(c) The results of HDR using Lamp sequence

Fig. 2. The results of HDR images using test sequences.

Fig. 2 represents the results of HDR image by using Debevec's method, Qtpfsgui, FDRTools, and the proposed algorithm. We can find that the result of the proposed algorithm removes the ghost artifacts. In particular, the result of Car sequence represents the enhancement of license plate. Because the proposed algorithm can remove ghost artifacts and enhance low illumination image, it can be applied to check the vehicle for anticrime. The test sequences are cropped and enlarged for clearer comparison as shown in Fig. 3, Fig. 4, and Fig. 5.

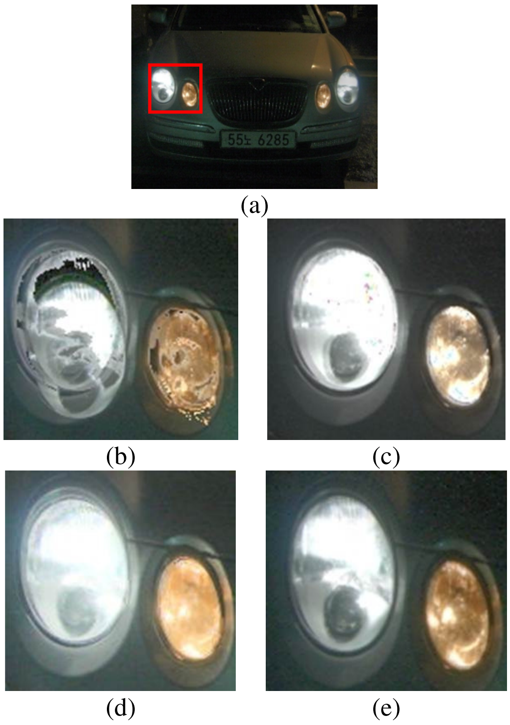



Fig. 3. Detail from HDR images (Car sequence); (a) Detail region, (b) Debevec's method, (c) Qtpfsgui, (d) FDRTools, and (e) Proposed algorithm.

Fig. 3(a) represents the region of crop and enlargement, Fig. 3(b)-(e) represent the results of HDR image. Fig. 3(b) shows the result of Debevec's method. Because this method is not able to compensate the camera movement, ghost artifacts are occurred in HDR image. Fig. 3(c) and Fig. 3(d) represent the result of Qtpfsgui software and FDRTools software respectively. These methods improve ghost artifacts rather than Debevec's method, however, ghost artifacts still remain. Furthermore, the texture of bright region is not expressed accurately. Fig. 3(e) represents the result of the proposed algorithm. Because the proposed algorithm compensates the camera movement by registering LDR images, ghost artifacts can be removed and the texture of bright region is also expressed accurately rather than Fig. 3(c) and Fig. 3(d).

Fig. 4 also represents the comparison the results of HDR image. We can find the ghost artifacts as shown in Fig. 4(b). On the other hand, Fig. 4(c) contains the tone mapping error at bright region, Fig. 4(d) contains the noise around edge. We can find that the result of the proposed algorithm can simultaneously remove the ghost artifacts and noise around edge.

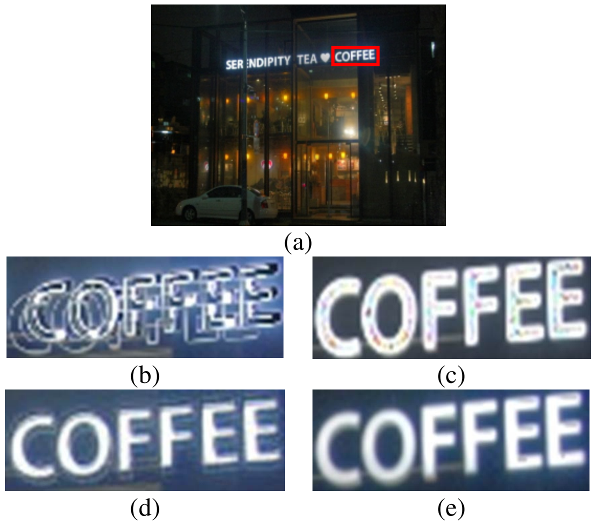



Fig. 4. Detail from HDR images (Café sequence); (a) detail region, (b) Debevec's method, (c) Qtpfsgui, (d) FDRTools, and (e) Proposed algorithm.

Fig. 5(b) also contains the ghost artifacts, Fig. 5(c) can expressed color accurately, since it contains tone mapping error. Although Fig. 5(d) is improved ghost artifacts rather than Fig. 5(b), the ghost artifacts still remain.

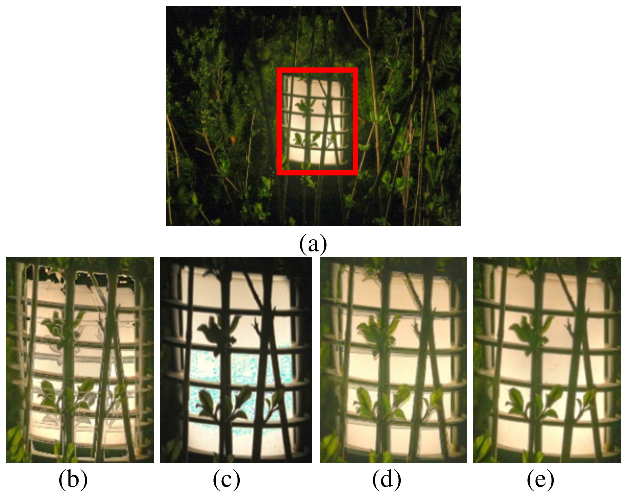



Fig. 5. Detail from HDR images (Lamp sequence); (a) detail region, (b) Debevec's method, (c) Qtpfsgui, (d) FDRTools, and (e) Proposed algorithm.

Table 1 represents the comparison of sum of motion between registered LDR images and unregistered LDR images. We can find that the proposed algorithm can reduce the difference of motion between LDR images by compensating the camera movement.

Table 1. Comparison with amount of motions between unregistered frames and registered frames

| Sequence | Unregistered | | Registered | |
|---|---|---|---|---|
| | Vertical | Horizontal | Vertical | Horizontal |
| Car | 1734 | 1778 | 1316 | 1371 |
| Café | 1218 | 1789 | 704 | 612 |
| Lamp | 1790 | 1207 | 723 | 685 |

## 4. CONCLUSIONS

In this paper, we presented a ghost artifacts removing algorithm for generating ghost-free HDR image in presence of camera movement. The existing method of generating HDR image contains restriction is that the camera must be kept still when acquiring LDR images. In order to improve this restriction, the proposed algorithm registers the LDR images using by ER algorithm to compensate the camera movement. The experimental results show that the proposed algorithm removes the ghost artifacts well rather than the Debevec's method and existing commercial products. For this reason, the proposed algorithm can be applied to various mobile imaging devices, such as handheld camera and mobile phone camera. However, the proposed algorithm contains computational load because of iterative estimation of geometric parameters. Therefore, the research has to carry out the optimizing the proposed algorithm for reducing the computational load and developing the algorithm, which can compensate the zoom-in and zoom-out movement. In addition, color enhancement is studied to enhance the color distortion occurring in tone mapping.

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