Visual Perspective based Exposure Compensation for 360◦ Virtual Reality Videos

Jae-Il Jung, Yongjin Kim, Jinhyoung Ahn, Sungrae Cho, Minchul Kim, and *Yongkuk Kim
Creativity Lab, Digital Media & Communications R&D Center, Samsung Electronics
33, Seongchon-gil, Seocho-gu, Seoul, South Korea

Abstract: We propose an exposure compensation algorithm for 360° virtual reality video, which considers viewer's visual perspective. Conventional algorithms force images to have the same and fixed exposure, but our algorithm finds dynamic exposures according to viewer's gazing point. We measure the Euler angles between a current gazing point and centers of stitched images on a virtual sphere, and optimize exposure compensation parameters based on the angles. These parameters are dynamically updated when viewer's head moves. Experimental results show that our algorithm successfully compensates exposure differences while keeping the original brightness.

1. Introduction

Virtual reality (VR) refers to a virtual environment which offers immersive experiences to viewers by showing 360° contents. The technology for VR is widely developed and the related market is expected to grow exponentially. Recently, many cameras capturing 360° video and photos have been released.

These cameras generally hold more than two cameras to capture multiple angle images, and stitch the images into a spherical panoramic image [1]. Such multiple camera based methods using image stitching achieve the better image quality than one omnidirectional camera, but can cause synchronization, parallax, and exposure mismatch problems [2].

The parallax problem is one of the main issues because simple 2D warps cannot account for parallax. These are only effective for scenes which are planar or the views which differ purely by rotation. Therefore, spatially-varying warping and post processing algorithms have been studied [3-5].

The exposure mismatch between neighbor images creates notable visual seams on a stitched image and which severely degrade immersive experience of VR viewers. Camera exposure depends on luminance of a view to be captured, and an image signal processor (ISP) in the camera controls it to get the best image quality. Since illuminations in views cannot be guaranteed to be the same, especially outdoors, exposure of each camera could differ.

To solve the exposure mismatch problem, Uyttendaele *et al.* developed local correcting and blending algorithms, which utilize a block-based transfer functions and smoother mapping between images [6]. This method can reduce the global exposure differences and handle local variations from lens vignetting.

M. Brown *et al.* proposed a gain compensation algorithm which solves for a photometric parameter, namely overall gain between images. This method measures differences in brightness over overlapping regions between stitched images and compensates each other [7]. It also can correct exposure mismatch using a simple quadratic objective function.

However, these algorithms were developed for the conventional image stitching which generates mosaic images, so the aim is to unify brightness of input images. Such algorithms calculate the overall photometric parameters and forces the images to have the same exposure even though the original exposure is the best for each view. Especially, they degrade brightness of all input images if there are severe exposure differences.

This problem is inevitable for the conventional image stitching fields, but it is possible to utilize visual property of humans in VR. Therefore, we propose an exposure compensation algorithm to preserve original brightness utilizing distinct characteristics of VR and visual perspective.

2. Visual Perspective based Compensation (VPC)

2. 1 Visual perspective and eye gaze in VR

Image stitching for VR has different applications as compared to conventional stitching. It creates a panoramic 360° image and viewers watch the image projected on a virtual sphere using VR devices. Hence, viewers are not able to see the entire stitched image at the same time.

It is generally known that the visual field of human eyes is 130°-135° vertical and 200° horizontal [8], hence regions projected on a virtual sphere behind a viewer do not affect the visual quality; these regions can be ignored for exposure compensation.

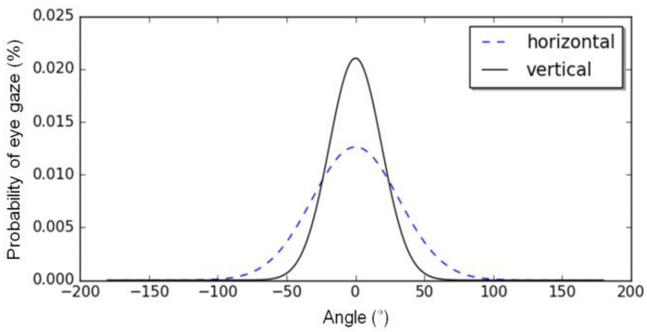


Figure 1. Probability of eye gaze with a fixed head.

In this paper, we assume the probability that a viewer gazes at a point without moving his head follows the Gaussian distributions as shown in Fig. 1. After finding an approximate gazing point from sensors of a VR device, we assign different weights to images according to the probability distribution and image positions on a virtual sphere.

2. 2 Gain compensation based on eye gaze

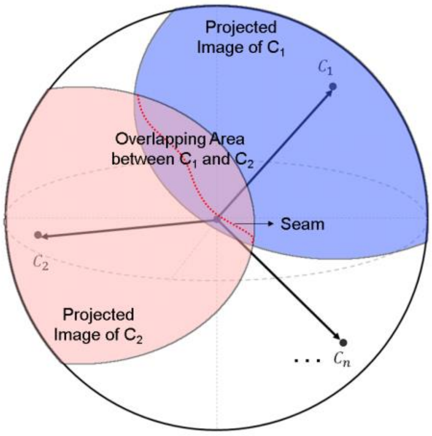


Figure 2. Projected images on a virtual sphere and overlapping area

For making 360° images, it is needed to project input images on a virtual sphere and to stitch the images on it. The input images should have overlapping areas and seams exist on these areas as shown in Fig. 2; seams can have various shapes such as a line, a curve, and an arbitrary form [9, 10].

We measure the exposure difference between images by analyzing the overlapping area and find the weights and correction factors for the current gazing point.

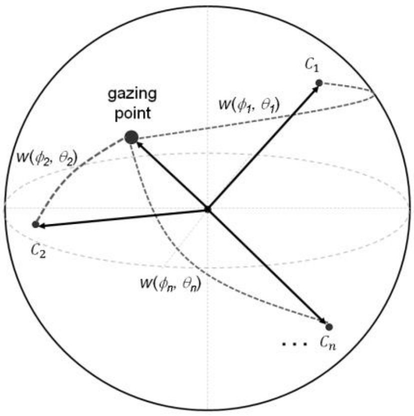


Figure 3. Weights for images located at different positions

Figure 3 depicts the centers of stitched images and the current gazing point. To calculate proper weights for the current situation, we measure the Euler angles between a gazing point and centers of stitched images on a virtual sphere. With this relation, the energy function is defined as

$$e = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} N_{ij}\left(E_{diff}(i,j) + E_{keep}(i)\right) \tag{1}$$

where N_{ij} stands for the number of pixels in an overlapping area between image i and image j. We discard saturated pixels since they have meaningless data and distort the further calculation, even though these are on the overlapping areas

In (1), the first term, E_{diff}, penalizes the intensity errors between images, and the second term, E_{keep}, keeps the gains close to unity. E_{diff} is based on the differences between gain-controlled pixel values and defined as

$$E_{diff}(i,j) = w_{diff}(\theta_i,\phi_i)\left(g_i I_{ij} - g_j I_{ji}\right)^2 / \sigma_N^2 . \tag{2}$$

I_{ij} is the mean of image i in the overlapping area with image j. The weighting factor, w_{diff}, makes E_{diff} ignore differences on invisible areas because the seams on invisible areas do not affect visual quality for VR viewers. It selects the greatest w_{keep} value between neighbors like

$$w_{diff}(i,j) = max\left(w_{keep}(\theta_i,\phi_i),\quad w_{keep}(\theta_j,\phi_j)\right). \tag{3}$$

The preservation term, E_{keep}, is defined as

$$E_{keep}(i) = w_{keep}(\theta_i,\phi_i)(1 - g_i)^2 / \sigma_g^2 . \tag{4}$$

Here, $w_{keep}(\theta, \phi)$ is a weighting factor with respect to the current gazing point and is defined as

$$w_{keep}(\theta,\phi) = \frac{1}{2\pi\sigma_h\sigma_v} exp\left(-\left(\frac{\theta^2}{2\sigma_h^2} + \frac{\phi^2}{2\sigma_v^2}\right)\right). \tag{5}$$

This factor is based on the input parameters θ and ϕ that represent the horizontal and vertical angles between an image center and gazing point as shown in Fig. 3. σ_h and σ_v are horizontal and vertical standard deviations as explained in 2.1.

(a) original image

(b) GC

(c) VPC

Figure 4. Extreme example having a wide dynamic range

The final gain parameters can be calculated by minimizing the function e, and these parameters are dynamically updated when a head moves. Since the prameters change continuously as the head moves, it does not cause an unnatural and sudden brightness change.

3. Experimental Results

3. 1 Extreme example of VPC

We experimented with our algorithm on challenging images with wide dynamic range between views, to show the effect of the proposed algorithm clearly.

The stitching results of the original images are shown in Fig. 4(a). We applied GC that M. Brown *et al.* proposed [2] and the result is shown in Fig. 4(b). GC degrades the contrast of both images, because the aim of the algorithm is forcing the images to have the same exposure. Since VPC compensates exposure according to eye gaze, it can show clear images dynamically as shown in Fig. 4(c).

3. 2 Original luminance preservation

For precise experiment regarding 360° videos, we used three cameras with wide-angle lens to capture three images, and calibrated these cameras using OCamCalib [11]. The captured videos were stitched on a virtual sphere, and projected them to equirectangular planes. We did not apply a high-level blending algorithm [12] to show seams clearly.

Figure 5(a) and Fig. 5(b) depict the original stitched image and overall luminance change according to the direction of eye gaze, respectively. As the gazing point moves from the darker region to the brighter region, the overall luminance becomes darker to keep the original exposure near the gazing point. The notable visual seam appears in the dotted box, but it is behind of a VR viewer; the proposed w_{diff} term makes the algorithm ignore visual seams in invisible areas.

To evaluate similarity to the original image subjectively, we measured the brightness of the six gray patches on the Macbeth charts and the results are shown in Fig. 6. "VCP (cam*x*)" in the legend means the results of VCP when the gazing point is at the center of cam*x*. We realize that the proposed algorithm preserves the image luminance near the gazing point while disregarding invisible areas.

Figure 7 shows mean absolute errors between the original and corrected images. It means that GC has the same and large errors at wherever a viewer gazes, but VCP can show much closer scene to the original image dynamically.

(a) original image

(b) VPC results

Figure 5. Overall luminance change according to the direction of eye gaze

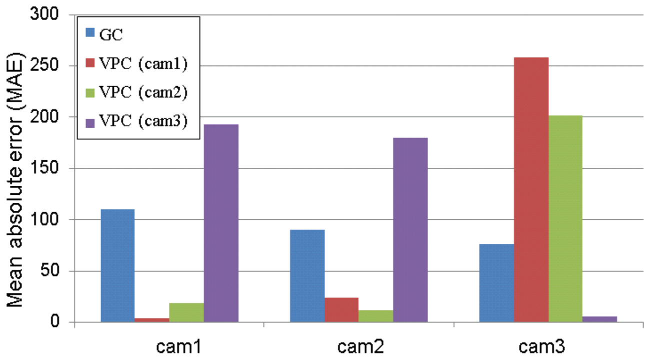


Figure 7. Mean absolute errors of GC and VPC according to gazing points

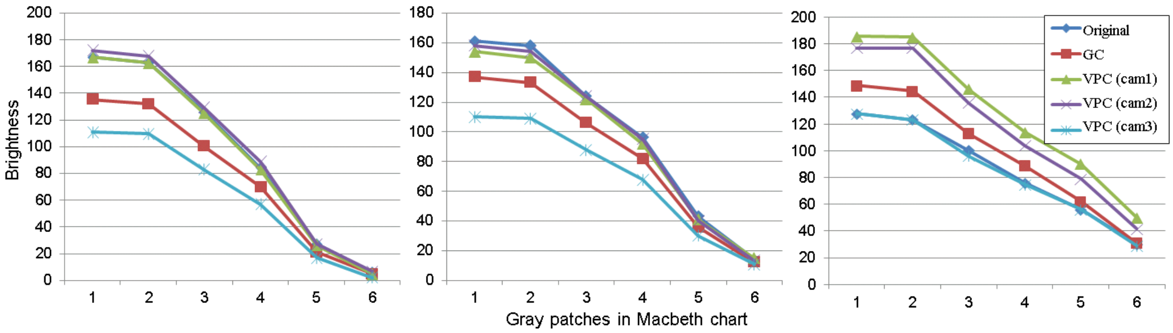


Figure 6. Comparison of luminances

3. 3 Additional test results

We additionally applied the proposed algorithm to ordinary scenes. Figure 8(a) is the stitching result of a "tower" image. Figures 8(b) and 8(c) show the results of GC and VPC, respectively. Figure 9 is the result of a "lobby" image having extensive saturated areas.

(a) original image

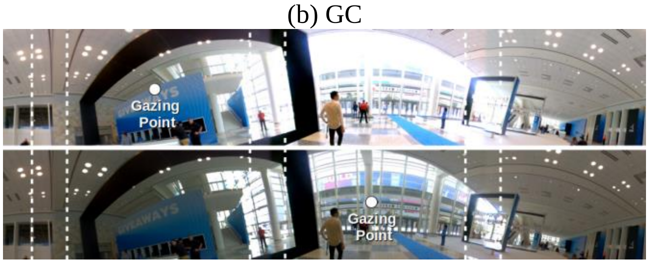
(b) GC

(c) VPC

Figure 8. Qualitative comparison on a "Tower" image

(a) original image

(b) GC



(c) VPC

Figure 9. Qualitative comparison on a "Lobby" image

As shown in the results, the severe mismatch disappeared in both algorithms, but the brightness of GC became darker or brighter than that of the original image, implying that GC compensate for deviations in exposure with the same values regardless of eye gaze.

4. Conclusion

In conclusion, for a VR scenario, areas rendered beyond the field of vision of the viewer do not need to be considered for exposure compensation, hence optimizing exposure compensation while considering the point of gaze and the centers of adjacent stitched images provides better results and much closer to the original images exposure. Therefore, we proposed the visual perspective based exposure compensation algorithm which utilizes distinct characteristics of VR and visual perspective. The proposed algorithm has wide applications in 360° video rendering for a better user experience.

References

[1] R. Szeliski, "Image alignment and stitching: a tutorial," *Found. Trends. Comput. Graph. Vis.*, vol. 2, no. 1, pp. 1-104, 2006.

[2] Z. S. See and A. D. Cheok, "Virtual Reality 360 Interactive Panorama Reproduction Obstacle and Issue," *Virtual Reality*, vol. 19, no. 2, pp. 71-81, 2015.

[3] F. Zhang and F. Liu, "Parallax-tolerant image stitching," *IEEE Conference on Computer Vision and Pattern Recognition*, pp. 3262-3269, 2014.

[4] J. Zaragoza, T. Chin, M. S. Brown, and D. suter, "As-projective-as-possible image stithcing with moving DLT," *IEEE Conference on Computer Vision and Pattern Recognition*, pp. 2339-2346, 2013.

[5] C. Chang, Y. Sato, and Y. Chuang, "Shape-Preserving Half-Projetive Warps for Image Stithcing," *IEEE Conference on Computer Vision and Pattern Recognition*, pp. 3254-3261, 2014.

[6] M. Uyttendaele, A. Eden, and R. Szeliski, "Eliminating ghosting and exposure artifacts in image mosaics," *IEEE Computer on Computer Vision and Pattern Recognition*, pp. 509-516, Dec. 2001.

[7] M. Brown and D. G. Lowe, "Automatic Panoramic Image Stitching using Invariant Features," *Int. J. of computer vision*, vol. 74, no. 1, pp. 59-73, Aug. 2007.

[8] G. Dagnelie, "Visual Prosthetics: Physiology, Bioengineering, Rehabilitation," *Springer Science & Business Media*, ISBN 978-1-4419-0754-7. 2011.

[9] A. Agarwala, M. Dontcheva, M. Agrawala, S. Drucker, A. Colburn, B. Curless, D. Salesin, and M. Cohen, "Interactive digital photomontage," *ACM Trans. Graph*, vol. 23, no. 3, pp. 294-302, 2004.

[10] A, Eden, M. Uyttendaele, and R. Szeliski, "Seamless image stitching of scenes with large motions and exposure differences," *IEEE Conference on Computer Vision and Pattern Recognition*, pp. 2498-2505, 2006.

[11] D. Scaramuzza. OCamCalib: Omnidirectional Camera Calibration Toolbox for Matlab.

[12] P. Perez, M. Gangnet, and A. Blake, "Poisson image editing," *ACM Trans. Graph*, vol. 22, no. 3, pp. 313-318, 2008.