Zi Siang See, Adrian David Cheok. (2015) Virtual Reality 360 Interactive Panorama Reproduction Obstacle and Issue. Virtual Reality, Volume 19, Issue 2, pp 71-81, Springer.
http://dx.doi.org/10.1007/s10055-014-0258-9

Virtual Reality 360 Interactive Panorama Reproduction Obstacles and Issues

Zi Siang See, Adrian David Cheok

Abstract

The research studies obstacles and issues for spherical panorama image reproduction. Virtual reality 360 (VR360) interactive panorama presentation involves accurately reproduced spherical panorama images which can deliver pre-produced image information of the real-world location that allows user-controlled interactivity in virtual reality digital platforms with up to three hundred sixty degrees of visibility. Spherical panorama image is also useful in various mixed and augmented reality applications. However, the photographic reproduction of spherical panorama image may tolerate various obstacles and issues that can cause visual abnormality. These can include parallax error, nadir angle difficulty, inconsistent white balance, insufficient dynamic range in multiple angle images, ghosting effect when working with high dynamic range imaging, high amount of multiple angle source images to manage correctly and overall lengthy acquisition time. Biased reproduction of spherical panorama would be inadequate to record and report authentic visual information. This case study investigation provides an overview of the occurrence of potential obstacles and issues with the intention of acquiring high fidelity spherical panorama photographic reproduction.

Keywords: Spherical Panorama, High Dynamic Range Imaging, Image Reproduction, Virtual Reality, Augmented Reality.

1. Introduction

There are virtual reality 360 (VR360) interactive panorama image presentations or augmented reality applications that must rely on accurately reproduced spherical panorama image or source content with least visual abnormality. Spherical Panorama with panoramic photographic technique has been discussed and explored by various studies (Jacob 2004; Arth et al. 2011; Andrews 2003; Felinto et al. 2012; Brown and Lowe 2006; DiVerdi et al. 2009; Gledhill et al. 2003), usually involving omni-directional camera setup or with multiple angles image acquisition for constructing a high resolution panoramic imagery. Interactive user-controlled spherical panorama has been possible in the example of QuickTime Virtual Reality (Chen 1995) or various interactive panorama applications (Jacobs 2004). The basic aim of a panorama is to reproduce the real world so skilfully that spectators could believe what they are seeing as genuine (Oettermann 1997); in fact, high fidelity reproduction is the key focus. Panoramic image can serve many functions including the main purpose of reproducing the visual elements of real-world scene (Benosman and Kang 2001; Guan et al. 2009). Such an utilization example can be seen in the technical usage for Mars Rover Curiosity (Ravine 2012) for archiving panorama images using multi-shot method. Imaging variables during the image reproduction process of spherical panorama can potentially tolerate various obstacles and issues that lead to undesirable visual abnormality. As a result, it is difficult to reproduce spherical panorama reproduction that is completely free from imaging errors. Augmented reality applications that require to work with spherical panorama source content is speculated to operate correctly only in conditions of having accurately reproduced imagery content

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(Warrington 2007; Arth et al. 2011; Ventura and Höllerer 2013; Felinto et al. 2012; Langlotz et al., 2012; Langlotz et al, 2014).

Parallax error can happen in spherical panorama photographic image reproduction (Diverdi et al. 2009; Andrews 2003) when working with more than two images to be combined or stitched together, in order to produce the expanded viewing coverage in the image. Parallax error can be introduced when two source photographic images are acquired from an inconsistent viewpoint. This can result in the foreground and background of the main subjects in the multiple images to have slight changes in viewing perspective (Brown and Lowe 2006). Such a parallax error that has slight differences in the viewing perspective would disallow multiple images to be combined correctly; therefore, usually visual elements in the photographed multiple angle images may be forced to compromise with certain levels of unwanted parallax error.

Nadir angle in multi-row configuration (Felinto et al. 2012; Gawthrop 2007) is where the nadir angle is difficult to be acquired correctly during the photographic process. Industrial convention configurations such as the spherical panorama photographic tripod head generically allows photography users to reproduce multiple angle images from the horizontal plane with acceptable precision control (Gledhill et al. 2003; Schmidt and Baumgart 2007); however, it usually does not allow acquiring the nadir angle image due to the obstacle of the equipment that has blocked the nadir viewing perspective.

Dynamic range in photographic image reproduction refers to the capability of reproducing visual luminance from the real-world scene (Debevec and Malik 1997). Usually shadow and highlight luminosity may exceed the recording capability of the film negative or digital sensor in camera. High dynamic range imaging (HDRI) method of combining multiple exposures can be useful for the reproduction of spherical panorama image (Reinhard et al. 2010; Felinto et al. 2012; Brown and Lowe 2006). However, HDRI is prone to introducing various associated obstacles and issues including ghosting error, inconsistent white balance and differently rendered HDRI appearance in multiple angle images.

2. Real-world Acquisition

Multiple angle images to be combined into a panorama image reproduction for having expanded view (Chen 1995; Jacob 2004; Gledhill et al. 2003; Diverdi et al. 2009; Felinto et al. 2012; Gawthrop. 200; Brown and Lowe 2006; Schmidt and Baumgart 2007) is also known as multi-shot or multi-row configuration; usually high precision handling is mandatory to maximize the accuracy of visual information reproduced. Figure 1 shows a generic process of multi-row configuration to cover zenith, horizontal and nadir angles.

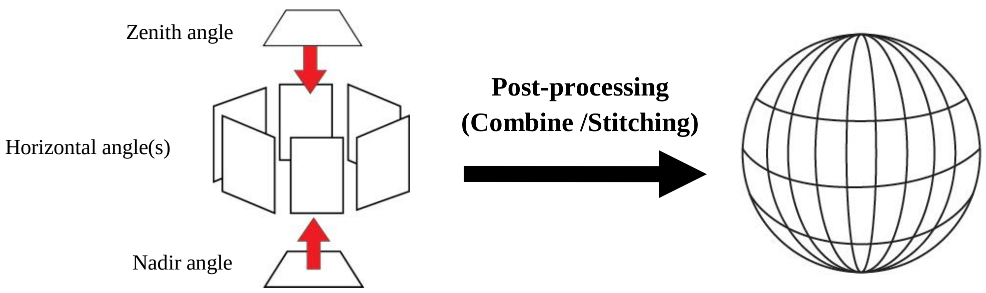

Figure 1. Generic multi-row process for combining multiple angle photographic images

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This case study investigates the occurrence of how imaging variables caused by obstacles and issues can happen during the spherical panorama image reproduction process, and then provide an overview assessment that is useful for current and future research studies that have the intention to overcome these difficulties from the photographic reproduction perspective. Case studies allows the observation to look into the complex cause and effect (Stake 1995; Yin 1994) of the potential obstacles and issues. There has been extensive research that triggers high interest on high dynamic range imaging (HDRI) (Reinhard et al. 2010; Debevec and Malik 1997) and panoramic vision (Benosman and Kang 2001).

This study has the intention of providing insightful field acquisition scenario for current and future studies that focus on the following interests:

- Spherical panorama study that requires working with HDRI.
- HDRI study that attempts to have high compatibility that matches with spherical panorama reproduction process.
- Augmented reality (AR) using high fidelity spherical panorama

The field acquisition is conducted with Nikon manufactured D3x attached with a 16mm full-frame fisheye lens. The equipment is being configured on Manfrotto 303SPH for acquiring multiple angle images as shown in Figure 2.

Figure 2. Field test that utilizes multi-row configuration

Figure 3 shows an example of spherical panorama reproduction for virtual reality 360 (VR360) interactive panorama for having digital image projection viewing on a multimedia mobile device. This sampling example however demonstrates parallax error and stitching error that can result in incapability to suggest accurate representation of the original real-world scene.

Figure 3. Inaccurately reproduced spherical panorama used on interactive panorama digital image projection

2.1 Spherical Panorama Image Reproduction and Observation

Real-world acquisition of spherical panorama image reproduction has been conducted to identify the major obstacles and issues. Figure 4 is a spherical panorama imaging sampling of location “FOM Entrance” reproduced from 8 image sequences. The multiple angle image sequences have been produced with conventional single exposure which is also known as low dynamic range (LDR) image. Observation has shown that the sampling of this spherical panorama contains parallax error due to less precise calibrated multi-row configuration as demonstrated in figure 5(a). Figure 5(b) magnifies nadir angle difficulty where the equipment situated at the bottom direction of the configuration has been captured. This leads to an undesirable visual occlusion in the location-based photographic reproduction.

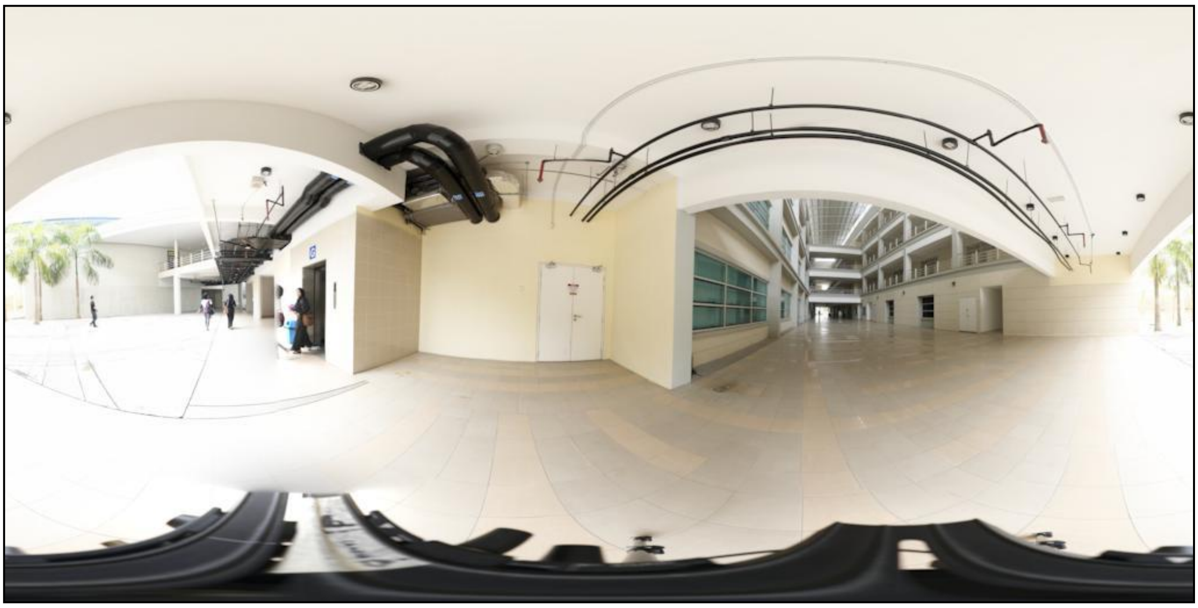

Figure 4. Spherical panorama image reproduction that contains several identical obstacles and issues

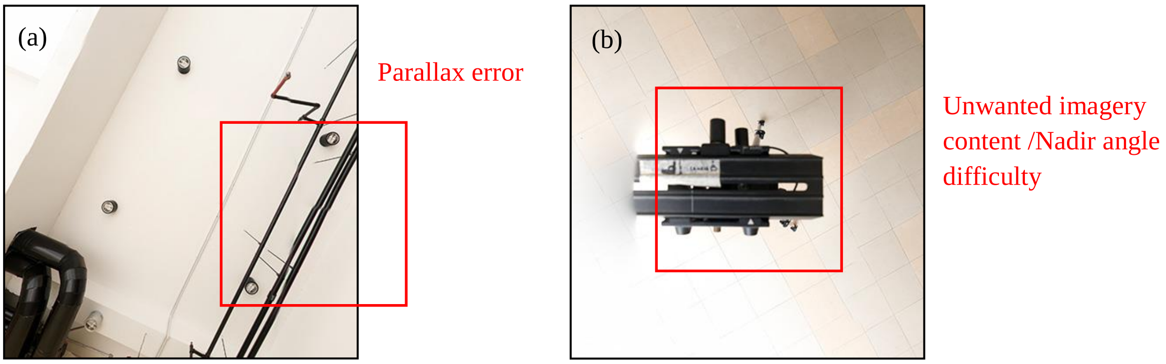

Figure 5. (a) Parallax error (b) Nadir angle difficulty

Parallax error, nadir angle difficulty and insufficient dynamic range can be observed in the spherical panorama reproduction in figure 4. As a consequence of these obstacles and issues, the entire representation of the spherical panorama reproduction is incapable of delivering adequate visual information of the location-based real-world scene.

Figure 6 and figure 7 from "Interpass Walkway" are the spherical panorama reproductions that have nadir angle difficulty. Figure 6(a) demonstrates the situation where equipment is visible at the nadir angle of the image, as observed with the cubic projection in figure 6(b). Figure 7(a) has been reproduced with extra nadir angle image to capture the nadir facade, but parallax error can be observed at the nadir angle during the post-processing outcome that contains geometrical bias in visual, as observed in figure 7(b) cubic projection.

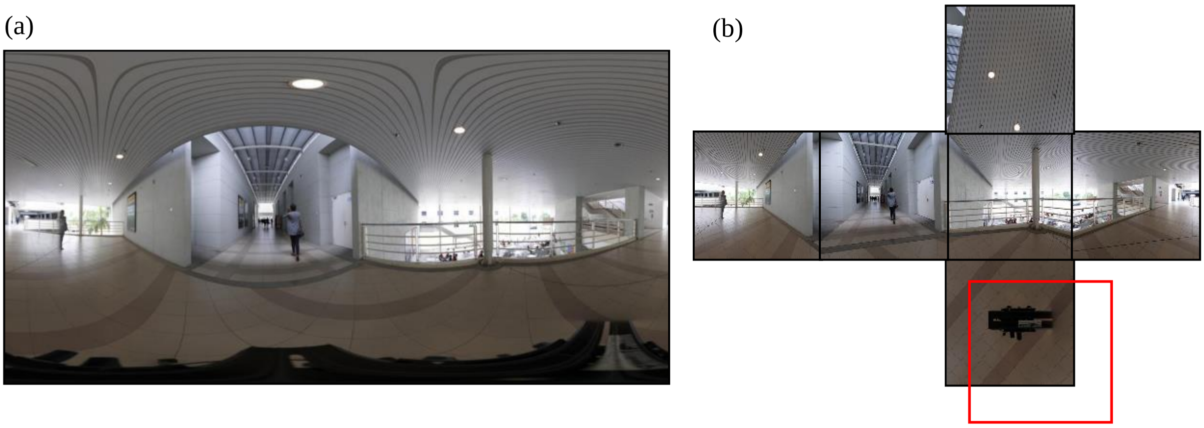

Figure 6. (a) Spherical panorama where equipment is visible at nadir angle (b) Cubic projection observation

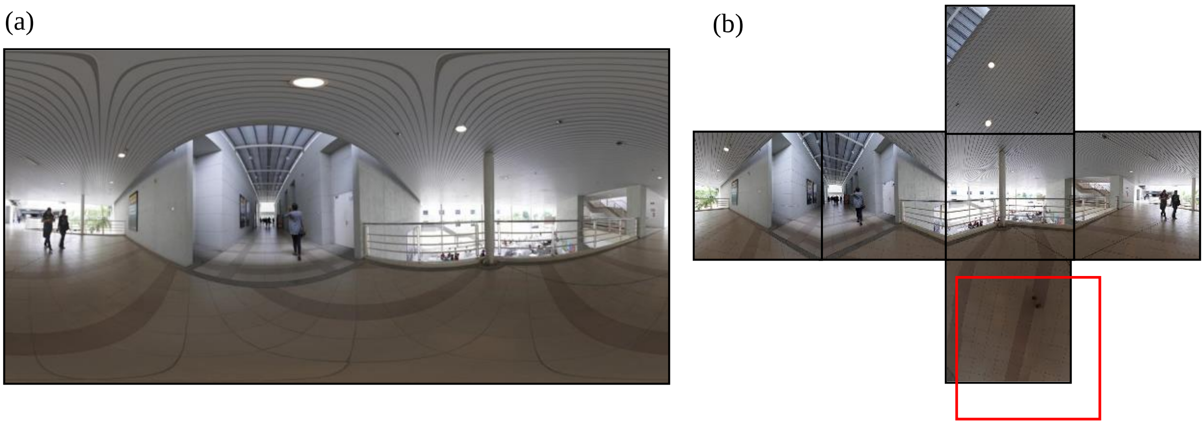

Figure 7. (a) Spherical panorama nadir angle with parallax error. (b) Cubic projection observation

Nadir angle has been found to be one of the angles that can be difficult for spherical panorama reproduction (Felinto et al. 2012; Jacob 2004). During the acquisition process, there are several factors being observed that can cause nadir angle difficulty in spherical panorama reproduction. Equipment such as the tripod or multi-row mounting situated at the bottom of the configuration will easily be captured in the multiple angle acquisition. In order to avoid the visibility of the equipment situated at the nadir of the configuration, additional image can be acquired from the original source of real-world scene. The intended extra nadir angle image has to be acquired with a stable configuration and it must accurately match the calibration of horizontal angles in order to provide a completeness of three hundred sixty degrees post-processing stitching correctness. Accurately reproduced spherical panorama without parallax error and sufficient dynamic range that can have adequate representation of the real-world scene is vital for providing authentic visual information for location-based documentation. Accurately reproduced visual information can satisfy the needs in cultural heritage preservation, architectural subject reproduction and scientific recording.

2.2 Dynamic Range Observation

This section provides assessment of dynamic range in spherical panorama production process. Figure 8 shows a simplified scenario observation of histogram pattern from low-key to high-key source of multiple exposures and the result of HDRI reproduced with middle-key histogram outcome. Usually, the darker images with shadow may demonstrate a low-key histogram and the brighter images with highlight may demonstrate a high-key histogram. Tone mapping reproduction, such as the industrial convention Photomatix Pro used in the sampling example of figure 8, would attempt to merge all sources of multiple exposure images into a HDRI reproduction with middle-key histogram. Fusing the multiple exposures into a HDRI that can maintain a middle-key histogram has the purpose of preserving the global or local tone reproduction in terms of extended luminance, however, it will be crucial to inspect if the entire set of multiple angle HDRI images with middle-key histogram would be appropriate for usage in spherical panorama reproduction.

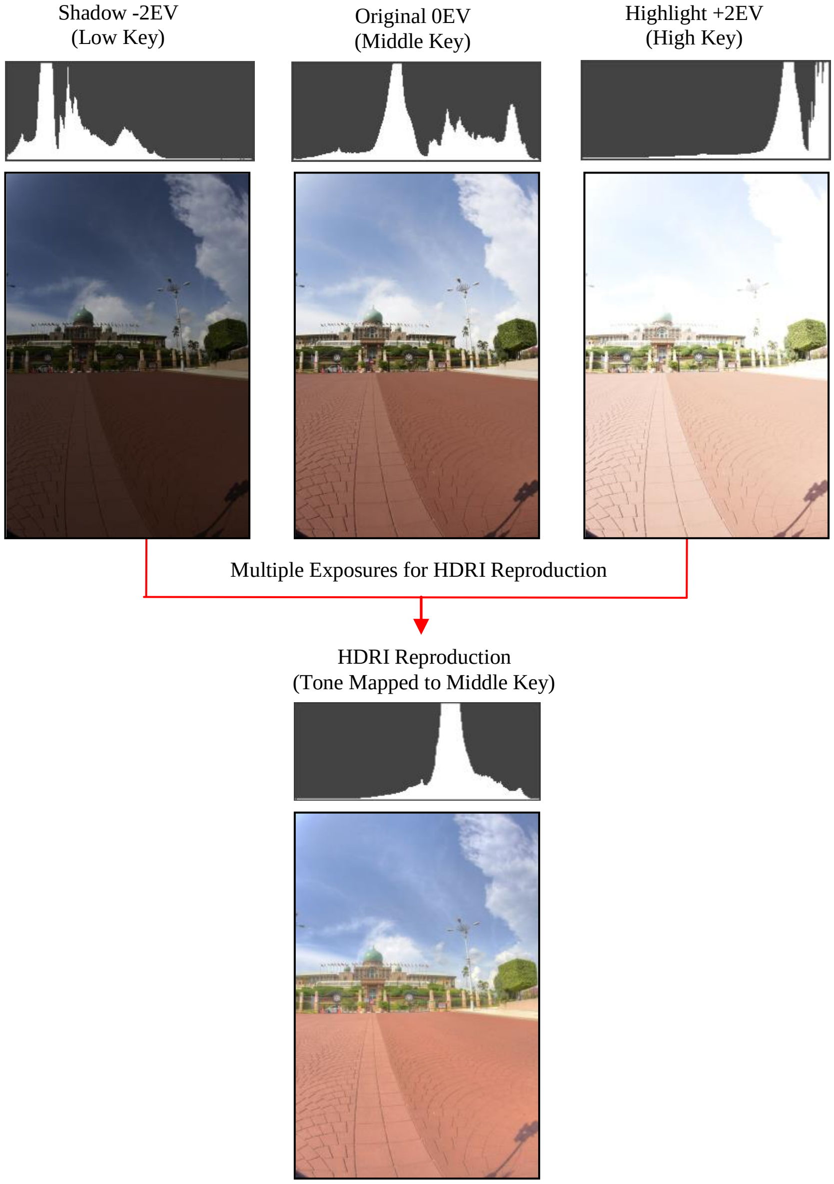

Figure 8. Observation of histogram pattern from low-key to high-key source of multiple exposures and the result of HDRI reproduced with middle-key histogram outcome

Figure 9 is spherical panorama reproduction sampling from "Putrajaya PM Office". The multiple angle images were reproduced with high dynamic range imaging (HDRI). Each HDRI image angle has been reproduced from 9 multiple exposures with 1 EV stop of increment from the shadow to highlight coverage. It is aimed to capture wider dynamic range in terms of extended luminance. HDRI is required when the lighting conditions at the real-world scene contains high contrast luminance, usually unable to be recorded by the single exposure photographic process, when using typical industry convention camera. For photographic image documentation, the analogue film image recording method exhibits limited amount of imagery information due to the limitations of resolution and dynamic range (Reinhard et al. 2010); with digital imaging method by combining multiple exposures into HDRI it can result in an increased, recorded and presented dynamic range in image. Figure 10 shows 8 angles of HDRI including the nadir and zenith acquired from the location-based real-world scene with histogram analyzed. Each angle of HDRI local reproduction during post-processing has attempted to merge the multiple exposures into a single HDRI based on what is the maximum pixel value that can be preserved for luminance. This process attempts to fuse the multiple exposures into a middle-key tonal reproduction as observed in the histograms for each image angle shown in figure 10. This can produce a result of inconsistent luminance reproduction in multiple angles when using HDRI for spherical panorama.

Figure 9. Multiple angle images were reproduced with high dynamic range imaging (HDRI)

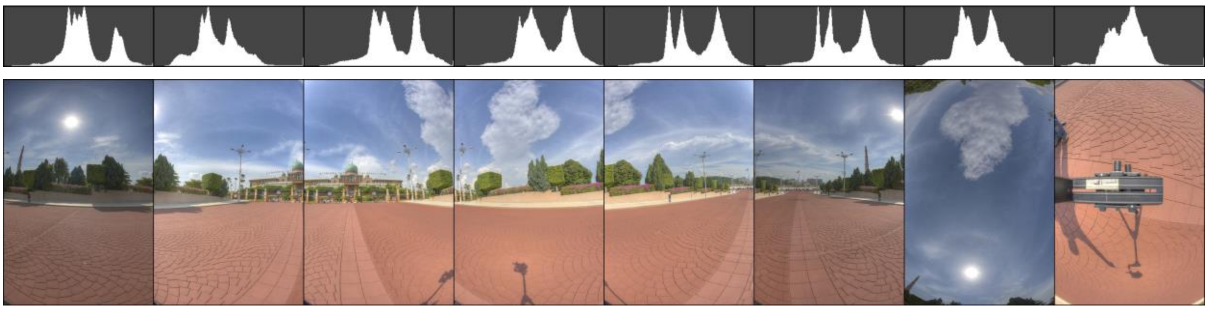

Figure 10. Inconsistent luminance reproduction in multiple angles using HDRI

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Dynamic range for image reproduction is crucial for defining the level of visual information that can be preserved in terms of luminance from shadow and highlight. Observing exposure range in photographic image reproduction is vital (Reinhard et al. 2010; Imatest 2012; Gardner 2012; Rehm 2009) to understand the amount of luminance information which would be preserved. Figure 11(a), (b) and (c) are the inspection processes of the acquired 18 image sequences sampling of Gretagmacbeth color checker chart, having the subject as images, were acquired in lab environment with fixed source of lighting. Table 1 shows the digital negative RAW processors being used for the test. The 18 image sequences were acquired from darker to brighter exposures for identifying the pixel values of Neutral 5 patch from the Gretagmacbeth color checker chart in a lab environment as indicated in figure 11(a), (b), (c), forming an observation of pixel value as shown is figure 12(a), (b) and (c) as supported by table 2 for the tested RAW Processors.

Image Sequence(s)	RAW Processor	Manufacturer /Developer
Sequence in Figure 11 (a), 12(a), 13(a)	(A) Capture One Pro 5	Phase One
Sequence in Figure 11 (b), 12(b), 13(b)	(B) Camera Raw 6.5	Adobe
Sequence in Figure 11 (c), 12(c), 13(c)	(C) View NX 2	Nikon Corporation

Table 1. Digital negative RAW processors being used for the test

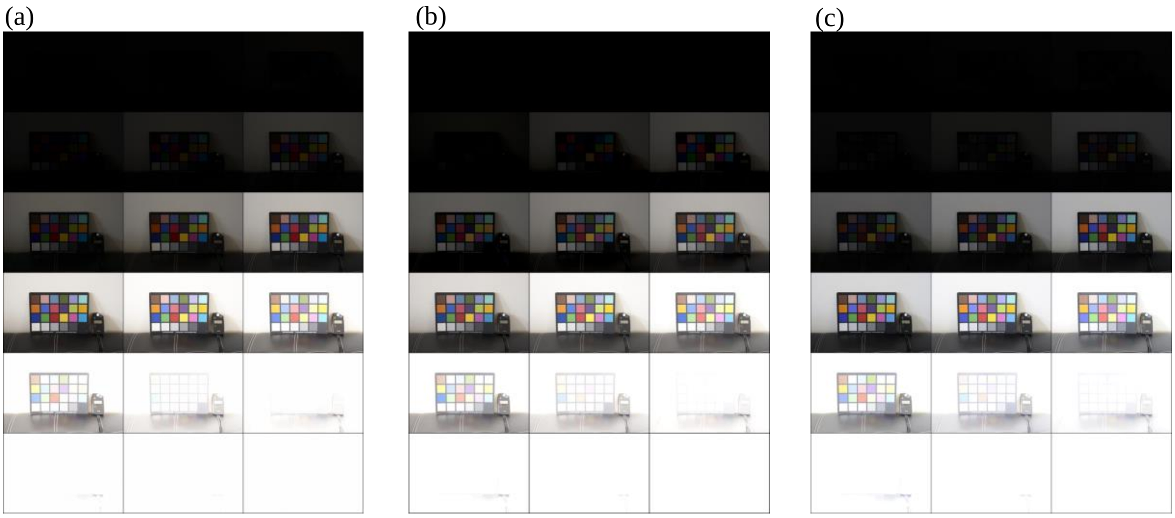

Figure 11. Inspection of the acquired 18 image sequences sampling of Gretagmacbeth color checker chart

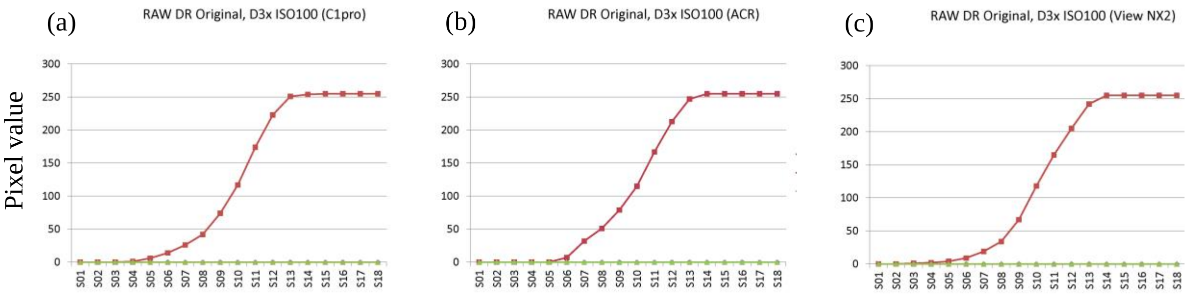

Figure 12. Pixel value of the acquired image sequences sampling of Gretagmacbeth color checker chart

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RAW Processor / Pixel Value	RAW Processor A Capture One Pro 5	RAW Processor B Camera Raw 6.5	RAW Processor C View NX 2
Sequence 01	0	0	0
Sequence 02	0	0	0
Sequence 03	0	0	1
Sequence 04	1	0	2
Sequence 05	6	0	4
Sequence 06	14	7	9
Sequence 07	26	32	19
Sequence 08	42	51	34
Sequence 09	74	79	67
Sequence 10	117	115	118
Sequence 11	174	167	165
Sequence 12	223	213	205
Sequence 13	251	247	242
Sequence 14	254	255	255
Sequence 15	255	255	255
Sequence 16	255	255	255
Sequence 17	255	255	255
Sequence 18	255	255	255

Table 2. Pixel value of image sequences tested by different RAW Processors

Figure 13 shows pixel value information is being sampled from the Neutral 5 patch of each image from the 18 sequences acquired as demonstrated in figure 11 and 12. The same set of image sequences are being processed and tested with 3 different RAW processors and indicated in table 2.

Figure 13. Pixel value information is being sampled from the Neutral 5 patch of each image from the 18 sequences acquired

The dynamic range observation has demonstrated that similar source images acquired may produce dissimilar pixel value outcomes as seen in figures 11 and 12. Overall exposure range is approximately 8.5EV produced from the camera configuration in this study, indicating that this would be the approximated exposure range that can be preserved and presented in the multiple angle image acquisition required by spherical panorama reproduction, when working with source images of LDR. Therefore, should the situation require dynamic range greater than the capability of the photographic equipment used, HDRI technique is recommended for spherical panorama reproduction. It can be assumed that a specific solution would be needed for having consistent luminance reproduction across multiple angles required by spherical panorama multi-row process.

3. Discussion

Several augmented research studies have been relying on using panorama image as source tracking content (Warrington 2007; Arth et al. 2011; Ventura and Höllerer 2013; DiVerdi et al., 2008; Wagner et al., 2010; Langlotz et al., 2012; Langlotz et al, 2014, Zang et al., 2012); however, obstacles and issues that has resulted in inaccurately reproduced panorama images can lead to ineffectively augmented and virtual reality applications. For instance, a panorama image reproduced from an actual location-based scene can be used for AR image-based tracking of the original real-world scene in real-time order. Authenticity of visual information from the source of panorama image reproduction is mandatory in providing virtual reality user experience with a sense of realism resembling the original real-world condition. The multi-shot or multi-row configuration used in the spherical panorama image samplings suggests parallax error should be minimized or entirely avoided during the photographic acquisition process without performing compensated correction during the post processing process. Inconsistency of photographic conditions across the multiple image sequence can be minimized with some of the following suggestions:

1) Manual decisions be made for selecting the appropriate photographic moment to avoid unwanted moving objects being photographically recorded.

2) GretagMacbeth Color Chart used for fixing a selected white balance can be consistently applied on the entire multiple image sequence, on the condition that natural lighting such as the sunlight of the real-world scene is maintaining a slow changing pace with a calm weather condition.

3) The time needed to acquire the entire set of multiple image sequences is suggested to be minimal, in order to avoid any unpredictable imaging variables such as any moving objects or fast changing weather conditions if the architectural subject involves any natural lighting.

4) Ideally all the image sequences required for constructing the spherical panorama image rendering can be acquired with clarity of imagery feature, in order to suggest a robust image stitching process via any spherical imaging processor.

The dynamic range in high contrast real-world scene such as a location-based subject of architectural context would be difficult to be recorded and presented using the conventional single exposure method. This study brings an important perspective of observing the phenomenon of inconsistent HDRI luminance reproduction for multiple angles required for constructing spherical panorama. Fusing multiple exposures into a HDRI that can maintain a middle-key histogram preserves global or local tone reproduction in terms of extended luminance; however, the resultant multiple angles with inconsistent luminance is observed as not being suitable for accurate spherical panorama reproduction. There are various approaches for HDRI (Reinhard et al. 2010; Debevec and Malik 1997; Felinto et al., 2012) that can produce different intended outcomes in each single image. It may be vital to take advantage of HDRI approach to preserve and present luminance information. It can be significant that the method and apparatus of high dynamic range imaging (HDRI) suitable to work with high fidelity spherical panorama reproduction can be explored with further studies.

The ideal situation to include selective moving subjects in the spherical panorama imagery can be manually managed, as it requires high attention, spontaneous decision making during the consideration in pre-visualization stage. The spherical panorama imagery reproduced from multiple angle images is observed to be moderately suitable for recording and presenting the photographic moment of a location-based subject, however on 'multiple moment basis' instead of 'single photographic moment'. Unpredictable moving objects cannot be appropriately recorded and presented using multiple angle images approach, as it may potentially create a minor extent of biased photographic interpretation such as for the usage of forensic and news reporting purposes. The situation of image manipulation correction during the post-processing stage, however, may affect the authenticity of architectural image reproduction to a certain degree. In such a situation the study considers that the nadir angle difficulty is a mistake that requires rectification.

Industrial convention of virtual reality wearable computer has become more accessible to consumers. Several recent developments of wearable virtual reality headsets has incorporated the main feature for use with a smartphone (Zeiss, 2014; Archos, 2014; Samsung, 2014); experiencing interactive panorama using a wearable head mounted display (HMD) would become feasible in terms of computing, affordable device and user application availability. Figure 14 shows a conceptual implementation of virtual reality 360 interactive panorama experience on a head mounted display powered by a mobile-based device or interchangeable computing module. Fundamentally, most of the interactive panorama systems may consider it important to work with high fidelity source of panorama image reproduction in order to record and present real-world elements with reliable information. We hope this case study can provide an in-depth empirical understanding for interactive panorama producers and users towards how obstacles and issues can be interrelated to each other. The ideal reproduction of spherical imagery content should be considered in whole instead of fixing a portion of the overall difficulty. Future studies may explore if virtual reality head mounted display to be used for interactive panorama can provide user experience beyond the limitations of vision and sound, these potential areas can include experiencing communications via the elements of smell and taste.

The next step in this study may focus on lean reproduction studies of spherical panorama that is facilitated with high dynamic range imaging (HDRI). The availability of visual information in terms of higher resolution when working with higher resolution image recording instrument for multiple angle images may allow greater viewing magnification of the spherical panorama content. Therefore the goal to obtain high fidelity reproduction is recommended to have low tolerance to visual abnormality for both technical configuration and human handling. The future development of the intended study can work on potential technical optimization on how spherical panorama reproduction with high authenticity can be operated using method and apparatus which require least amount of photographic production time and human effort.

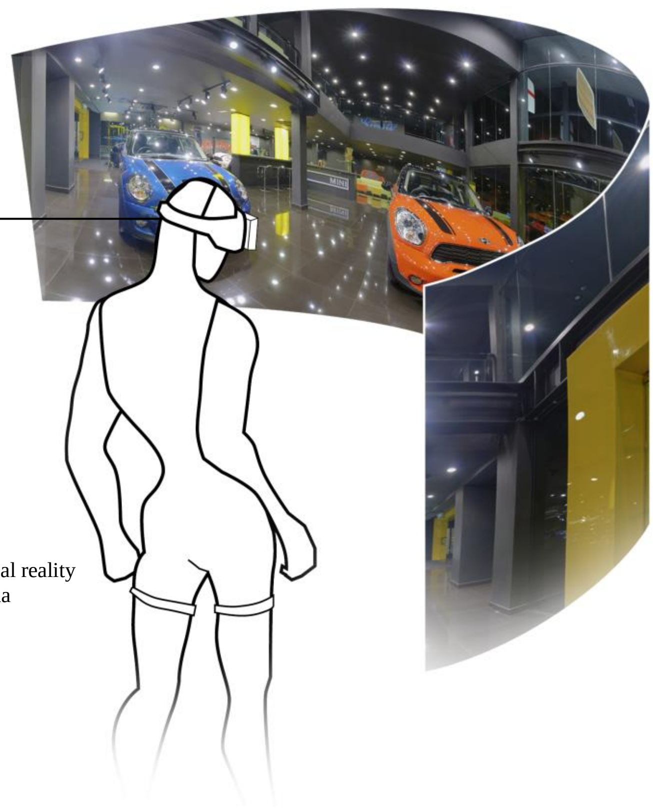

Figure 14. Virtual reality 360 interactive panorama user experience using a head mounted display powered by a mobile phone or tablet.

4. Implication and Conclusion

Virtual reality 360 (VR360) interactive panorama image presentations are becoming more widespread in recent years and has invited many changes in digital lifestyle. It especially improves the way we can interact with location-based images and access high fidelity visual information via various augmented and virtual reality development. This paper has observed how the occurrence of imaging variables caused by various obstacles and issues can happen during the spherical panorama image reproduction process. High precision method and apparatus calibration has been essential during the digital imaging workflow that involves the processes of pre-visualization, photographic acquisition and post-processing. Imaging errors or visual abnormalities that can be minimized or avoided include parallax error, white balance inconsistency, exposures inconsistency and ghosting effect caused by moving objects. Consistent luminance in multiple angles is critical to suggest accurate visual information being reproduced. For interactive panorama presentation and augmented reality applications, further studies can attempt to explore the method and apparatus that has the capability to operate precision reproduction process of spherical panorama facilitated with high dynamic range imaging (HDRI).

Reference

Andrews P (2003) 360 Degree Imaging: The Photographer's Panoramic Virtual Reality Manual. Rotovision.

Archos (2014) Archos VR Glasses: Jump into the mobile virtual reality world. http://www.archos.com/corporate/press/press_releases/US_Archos_VR_Glasses_PR_20141016.pdf Accessed 25 November 2014

Arth C, Klopschitz M, Reitmayr G, Schmalstieg D (2011) Real-Time Self-Localization from Panoramic Images on Mobile Devices, 2011 10th IEEE International Symposium on Mixed and Augmented Reality.

Benosman R, Kang SB (2001). Panoramic Vision: Sensors, Theory, and Applications. Springer.

Brown M, Lowe DG (2006) Automatic Panoramic Image Stitching using Invariant Features. International Journal of Computer Vision, 74(1), 59–73, 2007.

Chen E (1995) QuickTime VR - an image-based approach to virtual environment navigation. In SIGGRAPH '95.

Debevec PE, Malik J (1997) Recovering High Dynamic Range Radiance Maps from Photographs, SIGGRAPH, 369-378.

DiVerdi S, Wither J, Höllerer T (2009) All Around the Map: Online Spherical Panorama Construction. Computers & Graphics, 33(1), 73-84.

DiVerdi S, Wither J and Hollerer T (2008) Envisor: Online Environment Map Construction for Mixed Reality. Proceedings of the IEEE Virtual Reality Conference 2008, 19-26

Felinto D, Zang AR, Velho L (2012) Production Framework for Full Panoramic Scenes with Photorealistic Augmented Reality. XXXVIII Latin American Conference of Informatics (CLEI).

Gardner R (2012) Digital Tones and Exposure Zones, 2004, http://www.rags-int-inc.com/PhotoTechStuff/TonesnZones Accessed 27 July 2012

Gledhill D, Tian GY, Taylor D, Clarke D (2003) Panoramic imaging—a review. Computers & Graphics, 27(3), 435-445.

Guan X-Y, Shark L-K, Hall G, Deng W (2009) Distortion Correction for Immersive Navigation in Spherical Image Environment. 2009 International Conference on CyberWorlds.

Imatest (2012) Imatest - Using Stepchart, http://www.imatest.com/docs/q13/#dynamic Accessed 27 July 2012

Jacobs C (2004) Interactive Panorama. Springer.

Langlotz T, Wagner D, Mulloni A, Schmalstieg D (2012) Online Creation of Panoramic Augmented Reality Annotations on Mobile Phones. IEEE Pervasive Computing, vol.11, no. 2, 56-63.

Langlotz T, Nguyen T, Schmalstieg D, Grasset R (2014) Next-Generation Augmented Reality Browsers: Rich, Seamless, and Adaptive. Proceedings of the IEEE, vol. 102, no. 2, 155-169.

Oettermann S (1997) The Panorama. MIT Press, Cambridge, England.

Ravine M (2012) Mars rover camera project manager explains 2MP camera choice. http://www.dpreview.com/news/2012/08/08/Curiosity-interview-with-Malin-Space-Science-Systems-Mike-Ravine Accessed 11 August 2012

Rehm L (2009) D3x In Depth Review, 2009, http://www.dpreview.com/reviews/nikond3x Accessed 01 December 2010

Reinhard E, Heidrich W, Debevec P, Pattanaik S, Ward G, Myszkowski K (2010) High Dynamic Range Imaging (2nd Edition), Acquisition, Display, and Image-based lighting, ELSEVIER.

Samsung (2014) Gear VR. http://www.samsung.com/global/microsite/gearvr Accessed 25 November 2014

Schmidt L, Baumgart U (2007). What’s the meaning of VR Photography / VR Panoramas?. Art-documentation.com Accessed 21 August 2012

Stake R (1995) The Art of Case Research, Sage Publications, Thousand Oaks.

Ventura J, Höllerer T (2013) Structure and motion in urban environments using upright panoramas, Virtual Reality, June 2013, Vol 17, Issue 2, pp 147-156.

Wagner D, Mulloni A, Langlotz T, Schmalstieg D (2010) Real-time panoramic mapping and tracking on mobile phones. IEEE Virtual Reality Conference (VR) (2010), 211-218.

Warrington C (2007) Markerless Augmented Reality for Panoramic Sequences, MA Thesis submitted to Faculty of Engineering, University of Ottawa.

Yin R (1994) Case Study Research: Design and Methods, 2nd edition. Sage Publication, Beverly Hills.

Zang AR, Felinto D, Velho L. (2012) Augmented reality using full panoramic captured scene light-depth maps. Siggraph Asia 2012.

Zeiss (2014) VR One. http://zeissvrone.tumblr.com Accessed 25 November 2014

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