Pragmatic Manifestation of High Dynamic Range Imaging – A Review

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ABSTRACT

The real world images produce a range of brightness variations. However, the display systems used are able to operate on low dynamic range only i.e., they can reproduce only 8 bit data per pixel. This results in poor image quality as compared to what is visible to the human eye. Thus, in order to accommodate the vast dynamic range of natural scenes, a technique, referred to as High Dynamic Range Imaging(HDRI)has evolved in which the scenes having large intensity range can be captured unlike the traditional sensors. Therefore, HDRI is able to represent bright as well as dark portions in a scene faithfully. In this paper, the technology of high dynamic range imaging has been discussed. The various concepts in HDRI including the generation of high dynamic range image have been elucidated along with the storage formats used for HDR images. Further, various issues in obtaining quality high dynamic range images have also been conferred – like ghost artifacts and the effect on images due to motion of camera or objects. The paper also presents some of the future applications of the technology and is quite beneficial for researchers working in the domain of image processing, photography and computer graphics.

Keywords: High Dynamic Range Imaging, dynamic range, ghost artifacts, HDR image generation

1. INTRODUCTION

Images in the real world are richer in color as well as in brightness in comparison to their digital replica, besides having high local and global contrast levels between adjoining and remote objects respectively. The visual system has been able to deal with high levels of contrast and its existence in any scene leads to better perception. High Dynamic Range Imaging (HDRI) has evolved as a novel approach for representation of colors in digital media. HDRI techniques are now being used to cope up with the wide range of brightness levels and colors that are perceived by human eye rather than the limited range of colors made available by the display device. Theoretically, the High Dynamic Range (HDR) color space is considered to be the superset for all traditional color spaces as the displays/cameras fail to reproduce such a wide range of visible colors [1]. The inability of the digital cameras to capture real world images with huge dynamic range has made the HDRI technique much popular [2]. It is to be noted that the term dynamic range refers to the ratio between the smallest and the largest quantity in consideration. In the domain of image processing, the observed quantity is luminance [1].

HDRI is one of the fundamental techniques evolved so far which has altogether transformed the way how the visual content is operated and manipulated. HDRI, unlike conventional imaging, is able to reproduce such high levels of contrast in images. Further, these conventional images fail to represent general visual phenomenon viz., bright specular highlights, self-luminous objects, etc. They also contain less information necessary for the reproduction of visual glare and a temporary dazzle. High fidelity techniques are available in HDRI to provide faithful representation, storage and reproduction of these effects. HDRI technique has been able to provide much appealing and realistic visual content because in HDR images, pixels contain wide range of brightness levels and colors than any other existing visual systems [1]. HDR images can be acquired by multiple exposures, each adjacent frame having different exposure setting. These consecutive frames are then combined to generate a HDR image that can be viewed on common printers and display devices [2].

To meet all the requirements that the HDRI claims to attain, a standard data format is needed so that data can be efficiently transferred and processed on its way from acquisition to displaying. However, this is in contradiction to the wide range of RAW formats that are dependent on camera and sensors. Despite the fact that multiple 12-16 bit precision RAW formats are present in many modern digital cameras, it is common to convert the JPEG or MPEG at the initial stages of camera processing. This results in information losses with respect to human vision capabilities that cannot be recovered and thus limiting the further image processing, display and storage techniques. Apart from this, there are fundamental differences in the image format that have been used by the two imaging techniques. Image formats like PNG, JPEG, TIFF, etc., have been able to cope up with the device capabilities without paying much attention to the loss in visual information which cannot be displayed in these devices. Thus, these formats have been entitled as output referred or device referred because they are dependent on the capabilities of the display device. Evidently, those output referred image representations do not relate to the original photometric properties of the images depicted precisely. Consequently, high fidelity scene reproduction is difficult to achieve in devices with varying contrast range, color gamuts, peak luminance values and absolute lowest luminance values. A simple solution to the problem is offered by scene-referred image representation that encodes the original properties of the scenes depicted. The device is responsible for such a conversion from the representation directly corresponding to spectral radiance values to a device-suitable format. The rendering of the HDR content is done by the device as the entire information regarding the limitations as well as the viewing conditions is held by the device only. To highlight these drawbacks of the conventional imaging technology, it is referred to as Low Dynamic Range Imaging (LDRI). These limitations can be easily overcome by the imposition of pixel colorimetric precision that has been found to enable the representation of the entire range of colors present in real world perceptible to human eye. In turn, a variety of perceptual cues can be represented which cannot be achieved with conventional imaging techniques. In HDRI, images of a vast range of luminance can be represented that includes the photopic, mesotopic and scotopic vision. Thus, the colors may be perceived differently together with the loss in color vision during dark. The file formats in HDR exemplify scene referred encoding since they depict either spectral radiance or luminance instead of gamma-corrected pixel values that are ready to display. There can be problem in representing scene-referred images accurately in the name of tolerable quantization error. In the file formats of display-referred images, there is direct imposition of pixel precision by reproducing capabilities of display devices. For representing scene-referred images, only human visual system capabilities should be the constraint if data has to be stored efficiently and there should be no customization of accuracy to any specific imaging technology [1].

Summarizing, it is found that HDRI and the conventional LDRI differ in a way that HDRI can work only on high precision and device-independent data in order that there may be loss in quality at the display stage only and in case of failure of the device to reproduce the content faithfully. However, this is in contrast to the traditional low dynamic range imaging in which there is profiling of content for a specific device that is later stripped from valuable information at the image acquisition stage or at storage stage. Another important point of difference between HDR and LDR is the distinction in their pixel values. In general, there is a linear relation between the pixel values of HDR images and luminance, which can be defined as a photometric quantity that gives the description of light intensity perceived per unit surface area apart from its color. Since the spectral sensitivity of the cameras employed in capturing images is diverse as compared to luminous efficiency function of human eye, the pixel values of HDR images are almost by no means equal to luminance strictly. Although, HDR pixel values approximate to photometric quantities, there are certain sources that affirm a divergence from photometric measurements of the order of 10% in case of achromatic/gray surfaces up to 30% in colored objects [3].

1.1 HDR Image Generation

The easiest method to capture high dynamic range images comprises of taking several images and each image is taken at varied exposure settings. Even though LDR sensors may not be able to capture the dynamic range of luminance in a scene, it can be operated to cope up with the vast luminance range by making some changes in the exposure settings. As a result, every image is exposed in a different way such that a diverse luminance range can be captured in the progression. Later, all those images are combined together to form a single image by averaging the weight of the pixel values in the differently exposed images subsequent to the camera response and normalization by the change in exposure [4]-[7].

Ordinarily, this multi-exposure approach, as it is called, utilizes the entire resolution as well as the capturing capability of a camera to reproduce scenes of random dynamic range with sufficient number of exposures for every frame. Such a technique is found in several consumer products such as a cellular phone where it is identified as the “HDR-mode”. Contrary to all other capturing methods, this mode produces only one JPEG image that endeavors to preserve all the details obtained in multiple exposures. This can be achieved by fusion of numerous JPEG images which are captured at different exposure settings with every blending (or fusing) weight determined by a quality measure, e.g.; color distribution or local contrast [8].

1.2 Ghost Artifacts and Object/Camera Motion

There are certain problems that arise in the HDR images when obtained by the multi-exposure technique, like there may be misalignment of images due to the motion of objects in the scene or camera. The latter problem can be solved by aligning the input image derived from global homography by making use of robust statistics like RANSAC over the subsequent SURF [9] or SIFT [10] features. However, this approach does not work well if there is considerable parallax in a scene that cannot be reimbursed by global homographic transformation [1].

1.3 Storage of HDR Images

HDR images and videos prompt for high storage costs particularly when they are represented in floating-point format. The images that are obtained in digital cameras are generally stored as 24 bit JPEG images with 8 bits representing red, green, and blue each, thus offering resolution of 256 discrete levels for every channel accounting to 16 million levels in all. These levels can be easily differentiated by display devices. The usage of RAW format for capturing images might raise the number of discrete levels but still it won't be able to accommodate the complete dynamic range of the human visual system. To eliminate the limitations of the traditional JPEG file format, several new file formats have been introduced. All these file formats differ in the resulting file size as well as in their corresponding dynamic range. Thus, the need for better compression and representation of HDR video and images is felt [11].

1.4 HDR Image File Formats

A number of HDR file formats have been designed which are able to store HDR images. Some of them are described below:

1.4.1 RADIANCE HDR:

The very first format available for HDR images is Radiance HDR format that was first introduced in the RADIANCE rendering package in 1989. Exponent and mantissa are used to represent each pixel in this format with 8 bit floating points i.e., 32 bits for each pixel storage. Dynamic range associated with the format is of 76 order magnitude. The file extensions used for Radiance HDR format are .pic and .hdr. The storage file comprises of a short text header and run length encoded pixels. Those pixels are encoded by making use of RGBE or XYZE pixel formats. The two formats differ in the primaries they use; RGBE makes use of blue, green and red whereas XYZE makes use of CIE 1931 XYZ. Thus, the entire color gamut can be encoded by the XYZE format. On the other hand, RGBE lacks in the chromaticities lying within the red, green, blue color primaries triangle [12], [13].

1.4.2 OpenEXR:

Industrial Light & Magic has introduced a new format i.e. OpenEXR or the EXtended Range launching it with C++ open source library in 2002 [14]. File extensions for OpenEXR is .exr and this format is widely used in film production especially for producing special effects as well as in commercial applications. This format supports a huge dynamic range and precision of colors in comparison to the traditional 8 bit or 10 bit file formats. The OpenEXR format provides support for 16 bit / 32 bit floating point and 32 bit integer per pixel [1].

1.4.3 PORTABLE FLOATMAP:

This file format resembles floating point TIFF assigning 4 bytes to every channel. Four bytes are used in this format, one for sign, and other for exponent and the remaining bytes for mantissa.

1.4.4 PFS

It is not a file format; however, it is used for converting formats of HDR files into LDR images thus having similar functionality as the netpbm tool for LDRI. This format is not viable for disk storage and it is non-transferrable through slow networks.

1.4.5 JPEG-HDR

Since the HDR images have large intensity levels, 32 bit pixels seem to be less when the image resolution is increased in case of uncompressed HDR image. Besides this, the HDR formats discussed so far are not generally supported by image viewers and editors. The BrightSide came to rescue to tackle the problem by extending the HDR format to JPEG file format [11].

1.4 Tone Mapping

By tone mapping, we refer to a rendering process of scenes with high contrast and a vast color gamut on the target medium that has limited color reproduction and contrast. In general, this process comprises of transformation of HDR images into pixel values which can be represented on display devices [1].

Tone mapping, also referred to as tone reproduction, presents a method for mapping or scaling the high intensity luminance values of the original world on display devices with low dynamic range. Besides the compression in the luminance range tone mapping can also be utilized to mirror perceptual quality that can be reproduced by images in the real world. To prevent loss of luminance details during compression like brightness, contrast, fine detail, etc. tone reproduction operator is necessary [15].

Two technologies have been identified for tone mapping HDR images viz., Tone reproduction operator (TRO) and tone reproduction curve (TRC). Tone reproduction curve involves the techniques that operate on the pixel distributions whereas tone reproduction techniques include spatial manipulation of adjacent pixel values mostly at multiple scales [2], [16]. The full luminance dynamic range of a scene can be recorded by HDR radiance map in numerical format. However, it is observed that majority of the reproduction or visualization devices like printers, CRT monitors, etc. can produce images with the help of tone mapping methods that cannot be otherwise reproduced on the LDR devices. Tone mapping should be able to preserve the fidelity of the captured input information besides maintaining accuracy. High dynamic range imaging work flow is determined by the tone reproduction methods [17]. Some of the examples of TRO techniques include [18], [19].

1.5 Future Applications

High dynamic range imaging has been found to have astounding future applications particularly in digital photography. Some of the applications have been discussed in this section:

One of the applications of HDRI is sky capture i.e., monitoring of weather by international meteorological centers across the world to keep a close eye on the upcoming weather conditions. Sky capture requires extensive monitoring of the real world scene captured by cameras with high functionalities which preserve the actual world scenes and reproduce images that have close luminance intensity levels to that of the original scene. This cannot be obtained using common digital cameras but it requires something that possesses HDR functionalities together with sophisticated software which promise to meet the requirements needed in sky capturing. In addition to this, HDRI is important to architects and planners who show interest in customizing daylight performance of a building.

Glare rating is very important for physiologists and lighting experts. It is well known that the daylight glare has high luminance which is very difficult to characterize. However, with the introduction of HDRI, glare rating can be easily achieved using the various tone-mapping methods available [11].

The present day display devices such as LCDs, LEDs, etc. rely not only on the computational processing involved in the reproduction of a picture but also on display optics [20]. To achieve this, light attenuating layers have been stacked in LCD panels due to which every single pixel contributes to diverse directional light paths. Thus, compressive effect for the pixels in attenuating layers is achieved. Tomographic light when applied to the stack of these attenuating layers enhance the resolution but the image resolution at alternate pixels attenuates across all layers which can be easily achieved by means of high dynamic range imaging [21], [22]. This calls for extending dual modulation for handling several disjoint attenuators [16]. Furthermore, LCD panels having high refresh rates may serve as attenuating layers as they can display best possible patterns that are beyond critical flicker frequency of HVS. The resulting image is acquired by temporally integrating those rapidly changing patterns [22], [23]. This makes possible high angular expansion of the light paths transmitted such that motion parallax, binocular disparity as well as virtually accurate accommodation over large depth ranges turn to be feasible [24]. HDR display capability can be achieved by reducing angular resolution in compressive light field projection systems [25] and display devices [26] which improves the quality of such devices to meet the goal they have been targeting [1], [25].

From the above discussion, it can be comprehended that in future, it is possible to expand HDR technology further for capturing images and videos inexpensively and conveniently with improved quality. In addition to this, tuning display parameters at the user end can be made possible for the distribution of videos in HDR format in order to cope up with the hardware characteristics of display devices and the external lighting conditions. Further, it might be possible for the users to adjust the reproduction of videos as per their own preferences so that a balance is achieved among the reproduced details, brightness and contrast while presently the distributor decides about this information which is predetermined for the video streamed [27].

The purpose of this paper is to provide a brief analysis about the high dynamic range imaging technology. The paper is organized as follows: Section 2 deals with the review work that has been carried out in this field followed by Section 3 where the challenges in HDRI have been illustrated in the form of open issues. The paper concludes with Section 4 that contains the general overview of this paper.

2. LITERATURE REVIEW

The literature relevant to high dynamic range imaging was studied in order to develop an understanding about this technology. Various authors have presented their work on this subject and its other related aspects which have been given in this section.

The proposed work [2] has demonstrated numerous aspects that the well-recognized techniques i.e., the Naka-Rushton model of the Human-Visual-System (HVS) and the Logarithmic Type Image Processing (LTIP) model have in parallel. LTIP being a derivation of Logarithmic-Image-Processing (LIP) makes it seem replacing logarithmic function with ratios of polynomial functions. This connection has enabled the author to put forward an amalgamating framework for the problems associated with the HDRI. Accordingly, the standard irradiance map fusion is obtained by merging the exposures under LTIP framework resulting in HDR algorithm which is identified to offer better quality both in the subjective as well as in objective assessments. In this paper, the Naka-Rushton model responsible for light absorption in the human eyes like the CRF is associated with the cameras and this model has been found to be compatible with the LTIP model. The weighted sum is achieved from the input frames which becomes the characteristic of both exposure fusion and the irradiance map fusion. Thus, a new HDR algorithm is developed which is capable of acclimatizing exposure fusion operation similar to logarithmic function resulting in a reliable model in both practical and theoretical aspects. The details in the high luminosity areas are guaranteed by the LTIP operations. The proposed method upholds the ease of implementation emblematic to exposure fusion.

In [11], the author has put forward the theoretical analysis and applications of HDRI. HDRI is the latest technology introduced so far, making possible the acquiring of extended high dynamic ranges which otherwise was not possible. In HDRI, the pixels hold the real-world scene luminance values rather than the arbitrary pixel values. The HDRI images are captured using common consumer digital cameras but having the specification to capture a sequence of exposures thus allowing the HDRI images to store the corresponding sequences of the original scene. There is added functionality in the camera calibration. However, capturing HDRI images using a common consumer digital camera can be time consuming, but the availability custom HDR systems present in the process can be eased. The main focus is on the several recent technologies present in the field of HDRI and necessary steps to follow for generation of HDRI images along with the applications that would provide a way for future researchers.

Authors in [28] have presented a brief review of HDR techniques and various technologies associated with them. This paper comprises the in-depth introduction of necessary concepts associated with the perception in HDRI. The authors have discussed both the conventional and recent technologies present in HDRI. The capturing of HDRI image content from common digital cameras to HDR cameras with additional specifications, the generation of HDR image using numerous computer graphic methods along with the encoding followed by compression of HDR video and images have been covered in the paper. This paper also includes the tone mapping methods for proper display of HDR media on standard LDR displays. Inverse tone mapping leading to up scaling the captured content on HDR displays and the numerous display technologies available for HDR reproduction has also been talked about.

In [29], a research has been carried out based on a psychophysical experiment to conclude which tone reproduction operators are responsible for rendering actual world scenes. In the proposed paper, the authors using HDR display device have tested the closeness between linearly scaled images and tone mapped images on HDR display. The more an image is related to direct rendition on display, more is it said to be appropriate and distinct. In the proposed paper, the authors have conducted proper investigation to conclude whether the tone operators are successful to portray the real world scenes. The study carries the comparison of the results obtained from a reference scene displayed on a HDR display device. The main aim of this study was to investigate which of the operators were statistically capable of achieving the nearest score of reference scene being produced on high contrast ratio devices.

Tone Reproduction Curve (TRC) based tone mapping for display for HDR images on the LDR display devices has been introduced by the authors in [14]. The proposed paper has delivered a closed form solution to the optimized tone mapping introduced by the author in the past. In the past research carried by the authors, they have made use of the optimized two term cost function where the relative weighting associated with the two terms allows the viewers to control the appearances on the display device interactively, which provided only experiential solution to objective function present in previous research. In the proposed paper, the authors have been able to re-formulate the objective function providing a way to introduce closed form solution to the previously proposed two term tone mapping objective function. The new solution provided made this approach elegant mathematically, flexible, practically easier to devise and computationally faster. The methods which are based on the TRO are computationally more expensive as they include multiple resolution spatial processing. Other than this, TRO methods involve a number of operators which the viewer has to set thus making it hard to use. Unlike TRO, TRC doesn't encompass spatial processing resulting in reduced computational cost, consequently making it convenient to use in real time applications such as HDRI videos. In this paper, the TRC methods are found to avoid the artifacts like the halo effects as they are capable of preserving the intensity levels of real scenes. However, TRC is not free from limitations as it is also found to cause noticeable information loss in some images. In conclusion, the authors have established that both the TRC and TRO techniques have their individual leads and boundaries which make both of them to co-exist in probable future.

To attain perceptually precise tones in high dynamic range displays, a novel approach has been introduced by authors in [30]. In the proposed paper, a histogram approach has been utilized to curb the problems associated with reproduction of HDR images such as preserving visibility associated with HDR scenes. The introduced histogram adjustment method holds ground on local adaptation luminance present in a scene. For the matching in subjective viewing, the technique involves various models for glare, human contrast sensitivity, color sensitivity and spatial acuity. The main focus has been put onto the visibility of neighboring objects and contrast of image along with the viewer's response associated with their impression for both the virtual and real scenes which ought to be consistent. The authors have compared results with the previously introduced work and have presented the scope of the introduced technique in electronic photography and lighting simulation.

In the proposed paper [31], the authors have introduced a novel tone mapping technique related to the reproduction of high dynamic range scenes on the lesser dynamic range display devices. In this paper, HDRI tone mapping has been formulated as an optimization problem. A two term cost function has been presented: the first term being related to linear scaling mapping while the second term relates to histogram equalization mapping. The conjointly optimized term leads to mapping of high dynamic range image to a low dynamic image. Mapping results are controlled by the corresponding adjustments to be made in the objective function. The paper has also imparted a simple and fast proposal to solve the optimization problem reinforced by the competent demonstration of the results.

A novel learning based image processing approach has been put forward by the author in [32]. The proposed scheme maps high dynamic range scenes to low dynamic range scenes in order to reproduce them on standard LDR display devices. In this paper, the problem for display HDR images on LDR display devices has been framed as a quantization problem and an adaptive learning strategy has been employed to tackle it. Further, the employed learning strategy is accountable for preserving the fidelity of the reproduced scene as well as making use of the entire display levels available on the device. A quantizer has been designed by frequency-sensitive-competitive mechanism which is established on competitive neural networks. The proposed model has made use of optimized L2L2 distortion function which ensures conserving of visual characteristics of real scenes in mapped low dynamic images. The complete utilization of displayable levels is ensured by the said mechanism. A single variable has been utilized for controlling the display result. A thorough description of the scheme along with the results has been presented in the paper, thus demonstrating the effectiveness of the proposed model.

The author in [33] has studied various HDRI techniques with major emphasis on HDR images, generation of HDR images as well as on the numerous strategies related to image fusioning in which pictures are combined together to obtain an image with high luminance levels and less loss of information. In this paper, HDR approaches are considered as a set of techniques which are used to reproduce higher ranges of luminance by utilization of some added recognized techniques. Pictures captured using normal cameras without HDR specifications fail to attain such great luminance levels leading to loss of important information data.

The authors in [34] have addressed the ghost problem found in HDR imaging and have reviewed various solutions that have been proposed to tackle the same. In this paper, the suggested techniques have been associated and classified in detail. A quantitative evaluation of the various proposed approaches has been performed depending on their ability to detect ghost regions in the particular series of exposures. On the basis of fusion domain, required quantity of exposure, apparition map calculation, ability to discard phantom effect in the last HDR image and parameter setting, the various approaches have been categorized. It has been found that it is possible to detect high contrast movement(variation of the moving object from the background) properly whereas small/low contrast movements(similar colors of object and background) are difficult to find and thus have to be detected via entropy, multiple thresholding, prediction based and pixel order based approaches. In general, it is observed that there has not been a single best approach to tackle ghosting effects in HDR images and the method to be selected depends upon user's requirement. In order to eliminate the artifacts produced as a result of moving objects, iterative approaches can be used but they have proved to be computationally expensive. Exposures that are affected by ghost effect resulting from combining are removed by the approaches offering satisfactory results with low complexity. A suitable approach is needed at the ghost detection step in order to keep the moving object at static location in the combined HDR image. This paper has proposed a process which can capture HDR image without introduction of ghost artifacts. For static objects, proposed method is found to produce successful results in evading ghost artifacts. Even if the moving objects modify considerable region of a scene, the proposed approach proves to meet the requirements of HDR imaging in various scenarios.

In [35], the author has investigated numerous HDR techniques and finally put forward a novel HDR model. The HDR model has been developed to meet the adaptation criteria. The main goal of the proposed paper is to reduce the information loss during conversion from LDR to HDR, which has been attained by considering extension in the intensity range of a digital device (camera). The new HDR model has been developed which focuses on attaining information without forfeiture of real characteristics of a scene. The proposed model has been compared in terms of usability, photo-realistic quality of the picture and the associated computational cost with the numerous techniques discussed in the paper and has been found to most preferable and adaptable of them all.

3. OPEN ISSUES

After performing an analysis on the high dynamic range technology, several drawbacks have been found to be present in the high dynamic ranges images obtained. Those have been discussed in the literature review of this technology, some of which have been enlisted below:

- The radiance map obtained in HDRI has been found to record the entire dynamic range of a scene numerically. However, majority of the reproduction devices e.g., printers or CRT monitors have a limited dynamic range of images that they can reproduce, which is quite small than the radiance map dynamic range [1], [8], [11], [15], [17], [29], [33].
- When multiple images are fused into a radiance image during image generation process, there are issues in the reproduced images because of the motion of objects and camera in view of the fact that a stationary scene is assumed [1], [9], [10], [34].
- Another problem in the reproduced HDR image is the presence of ghost effect which makes a single object to appear several times in a scene simultaneously [34].

4. CONCLUSION

High Dynamic Range Imaging has been explicated which is a technique that makes it possible for low dynamic range display devices to present high dynamic range images that closely resemble real world scenes. HDRI technology is found to have its influence in the imaging industry in near future owing to the enhanced image quality and powerful ability to represent images faithfully. The various fields in which HDRI can be of utter importance have been realized to be next generation broadcast, digital photography or digital cinema. Moreover, the future directions of HDRI applications have also been discussed.

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