UNIVERSITI PUTRA MALAYSIA

A MODIFIED CONTRAST LIMITED ADAPTIVE HISTOGRAM EQUALIZATION FOR HIGH DYNAMIC RANGE IMAGES

TUNG LI QIAN

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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February 2012

Chair: Suhaidi Shafie, D.Eng

Faculty: Engineering

Tone mapping was originally used in the field of art where artists make use of a limited palette to depict high contrast scenes. The purpose of tone mapping is to display images or videos that correspond to the visual impression of an observer when watching the original scene by reproducing contrast and brightness between the original scene and the output device.

However, the dramatically reduction of contrast and brightness induce a loss of contrast resulting in a loss of detail visibility. As a result, a fully automatic local tone mapping algorithm was introduced to increase the local contrast and reduce the loss of visual visibility. The algorithm was written by using MATLAB software.

The local tone mapping method is based on the modified contrast limited adaptive histogram equalization (CLAHE) method. The tone mapping algorithm was first

compressed using global tone mapping method. The image was then segmented into smaller parts using pixel-region-based image segmentation method. The segment regions were processed to become masks using morphological method (opening and closing method). Every mask's clip limit was then decided according to the variance and mean. This step alleviates the artifacts introduced by the original CLAHE algorithm. Original CLAHE only have one clip limit and apply to each tile but the modified CLAHE method applied different clip limit in different mask in order to expand the dynamic range of the image. Lastly, the interpolation process was then applied to the entire image to remove the artificially induced tile border.

For assessment, a subjective and an objective evaluation were conducted to evaluate the performance of the tone mapping algorithm. For subjective evaluation a survey was conducted to compare the fifteen images that had been processed by Reinhard's, Drago's, Ward's and proposed tone mapping operator. For objective evaluation, visual difference predictor (VDP) was used to compare the difference between the HDR image and the tone mapped image. The generated probability map of the proposed tone mapped algorithm was then compared with the generated probability map of Ward tone mapping algorithm. Both results show that the proposed tone mapping algorithm produces images with good visual quality by retrieving more detail and local contrast in the image if compare with other tone mapping operator.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai menemuhi keperluan untuk ijazah Master of Sains

SATU PENGUAHSUAI KONTRA TERHAD ADAPTIF HISTOGRAM PENYAMAAN UNTUK JULAT DINAMIK TINGGI IMEJ

Oleh

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Pemetaan warna pada asalnya digunakan dalam bidang seni di mana artis-artis menggunakan palet yang terhad untuk menggambarkan pemandangan kontras tinggi. Tujuan pemetaan warna adalah untuk memaparkan imej atau video yang berpadanan dengan kesan visual seseorang pemerhati semasa memerhatikan pemandangan asal dengan menghasilkan semula kontra dan kecerahan di alat paparan yang bersamaan dengan pemandangan asal. Walaubagaimanapun, pengurangan drastik kontra dan kecerahan mendorong kepada kehilangan darjah penglihatan visual. Akibatnya, logaritma pemetaan warna tempatan sepenuh automatik telah diperkenalkan untuk meningkatkan kontra tempatan dan mengurangkan kehilangan penglihatan visual. Algoritma ini ditulis dengan menggunakan perisian MATLAB.

Kaedah pemetaan warna tempatan adalah berdasarkan cara penyamaan histogram penyesuaian kontras terhad (CLAHE) yang telah diubahsuai. Algoritma pemetaan warna tersebut dimampatkan terlebih dahulu dengan menggunakan kaedah pemetaan

warna global. Imej tersebut kemudian dibahagikan kepada bahagian yang lebih kecil dengan menggunakan kaedah pembahagian imej berasas piksel-rantau. Rantau bahagian telah diproses dengan menggunakan kaedah morfologi (pembukaan dan penutupan). Had klip setiap topeng kemudiannya diputuskan mengikut varians dan min. Langkah ini mengurangkan masalah artifak yang diperkenalkan oleh algoritma CLAHE asal. CLAHE asal hanya mempunyai satu had klip dan digunakan atas jubin masing-masing tetapi kaedah CLAHE yang diubahsuai menggunakan had klip yang berbeza dalam topeng yang berbeza bagi memperluas julat dinamik imej. Akhir sekali, proses penyelaan kemudiannya digunakan kepada seluruh imej untuk mengeluarkan jubin sempadan buatan teraruh.

Untuk penilaian, satu penilaian subjektif and satu penilaian objektif telah dijalankan untuk menilai prestasi algoritma pemetaan warna. Bagi penilaian subjektif, sebuah kaji selidik telah dijalankan untuk membandingkan lima belas imej yang telah diproses oleh Reinhard, Drago, Ward dan algoritma pemetaan warna yang dicadangkan. Untuk penilaian objektif pula, peramal perbezaan visual telah digunakan untuk membandingkan beza antara imej HDR and imej pemetaan warna. Peta kebarangkalian yang dihasilkan oleh algoritma pemetaan warna yang dicadangkan telah dibandingkan dengan peta kebarangkalian yang dihasilkan oleh algoritma pemetaan warna Ward. Kedua-dua hasil menunjukkan algoritma pemetaan warna yang dicadangkan menghasilkan imej dengan kualiti visual yang baik dengan mengembalikan lebih banyak butiran and kontras tempatan dalam imej berbanding dengan algoritma pemetaan warna yang lain.

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I certify that a Thesis Examination Committee has met on 22 February 2012 to conduct the final examination of Tung Li Qian on his (or her) thesis entitled "**Modified Contrast-Limited Adaptive Histogram Equalization For High Dynamic Range Images**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

TUNG LI QIAN

Date: 22 February 2012

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LIST OF ABBREVIATIONS

CLAHE: Contrast Limited Adaptive Histogram Equalization

CRT: Cathode Ray Tube

HDR: High Dynamic Range

HVS: Human visual system

LCD: Liquid Crystal Display

LDR: Low Dynamic Range

LED: Light Emitting Diode

PPD: Panel display

SDR: Standard Dynamic Range

VDP: Visual Difference Predictor

CHAPTER 1

INTRODUCTION

This chapter briefly introduces the tone mapping techniques which can be used to reproduce the high dynamic range (HDR) images. Differences between the standard digital image representation and the new high dynamic range imaging, the dynamic range for scenes and display, and the global and local tone mapping are explained too. The objectives of the research, problem statement and the thesis organization are also described.

1.1 Tone Mapping

Tone mapping was originally designed for the field of art where artists make use of a limited palette to depict high contrast scenes. Then this technique was later developed for the use of photography and television (K. Devlin, 2002). The purpose of the tone mapping is to display images or videos that correspond to the visual impression of an observer watching the original scene. Tone mapping also reproduce the contrast and brightness between the original scene and the output device.

For good image reproduction, tone mapping must mimic the way the human visual system (HVS) processes light information. The environment is full of wide range levels. HVS can have the ability to instantaneously and seamlessly adapt to scenes with a HDR scene that can exceed from 0.0001 to more than 10000. Examples of scenes and their approximate level is given in Figure 1.1 (Johnson, 2005).

Figure 1.1: Examples of scenes and their approximate level

1.1.1 Human Visual System

As mentioned in the previous section, the HVS system has almost 10 orders of magnitude. Studies have shown that the retinal receptors have a dynamic range as high as 10 orders of magnitude (Kuhna, 2011). Scene radiances are captured by the rods and the cones in the retina and passed further to the visual pathway. However, the optic nerves which transmit the visual signal only have a dynamic range magnitude of 2 orders (Johnson, 2005). This discrepancy can be explicated by a combination of visual phenomena processed by the HVS. The overall process is often defined as human visual adaptation (E. Reinhard, 2005). HVS adapts the illumination conditions by changing the diameter of the pupil depending on the light that enters the eye. Besides, the cones adapt their sensitivities to the mean luminance in the field of view. This is given by total retinal illumination and finally the local adaption modulates local contrasts as HVS gaze visually scans the scene. Figure 1.2 gives a general plan of the human eye and the retina with the names of their principal parts.

The image that had been captured is usually defined as linear with respect to scene-referred coordinate because their pixels have a relation to the radiance in a scene. Therefore, the main objective of tone mapping is to obtain an image from a scene referred coordinate while maintaining a perceptual match between the real scene and the displayed image, as shown in Figure 1.3. The figure shows the HVS processes the scene radiances in a non-linear manner through different adaptation processes. It forms a percept where all details are visible. Electronic devices capture the scene radiances linearly. A tone mapping operator is necessary to non-linearly encode the image as well as to map it to the display characteristics. This is to ensure that the displayed image corresponds to our memory of the original scene.

Figure 1.4 shows the difference between image captured by the camera and the scene that the observer had seen. The image that the camera captured looks too dark and loses massive amount of detail. Comparatively, the scene that the observer had seen has more contrast in the shadow and preserves more detail.

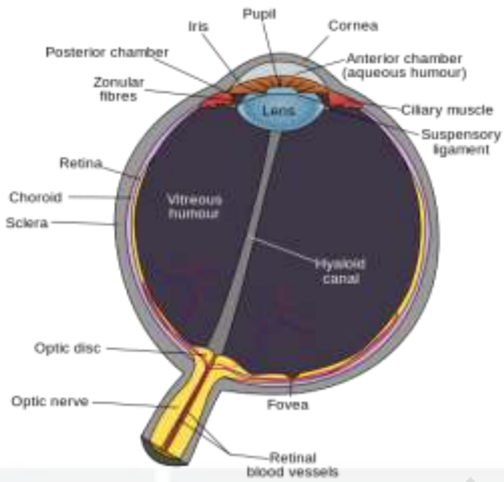

Figure 1.2: The general plan of the human eye and the retina with the names of their principal parts. (Original image of the eye courtesy of Rhcastilhos, Wikimedia Commons.)

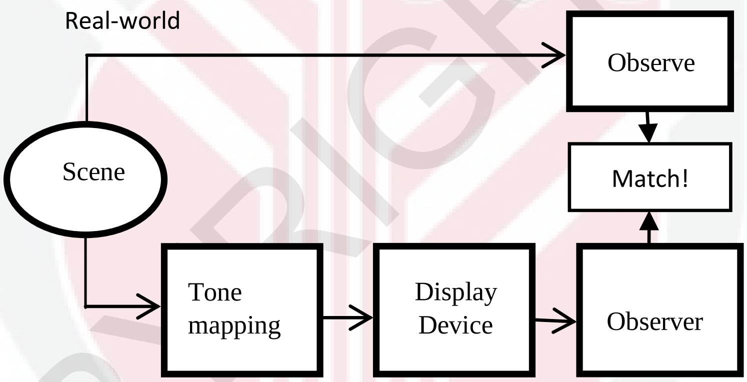

Figure 1.3: Perceptual match between a real world scene and displayed image.

Figure 1.4: Left: Image that is captured by the camera

1.1.2 The Dynamic Range of Scenes and Displays

Tone mapping can also be used to match the dynamic range scene with the display device. Dynamic range of a digital image can be defined as the contrast ratio between its brightest part and the darkest part while dynamic range of a scene is the luminance ratio between the brightest and the darkest part in the scene (E. Reinhard, 2005). Scene radiance can be measured using luminance, given in candela per meter square (cd/m^2). When the dynamic range of the digital image is lower or higher than the dynamic range of a scene, tone mapping process will either expand or compress the luminous intensity.

The dynamic range scene can be defined as the ratio of the luminance of the brightest color (white) to that of the darkest color (black). The average contrast ratio of those natural scenes is said to be 1:160. For scenes with fog, the contrast ratio is lower than the average ratio but outdoor scenes can reach the ratio of 1:1000 (Hunt, 1995). The natural scene is considered being a low dynamic range (LDR) when its dynamic range is lower than the output device. In order to view the LDR scene in the output device, the input image should be expanded to fit the output device. For the scene's dynamic range to be approximately the same as the output device, it can be defined as standard dynamic range (SDR). For the high dynamic range (HDR) scene, the dynamic range of the input image far exceeds the output device. As a result, certain parts of the displayed image will be clipped during the capturing process. The most typical HDR scene is a view of indoor room with visible scene outside the window.

Meanwhile, most of the conventional output display devices in the market are plasma panel display (PPD), cathode ray tube (CRT), liquid crystal display (LCD) and light emitting diode (LED) display. These output display devices are classified as standard display and their dynamic range is standard as oppose to HDR display which have a much larger dynamic range. Dynamic range of those displays is generally from 1:100 to 1:1000. For current technologies, dynamic range of the printer is typically from 1:50-1:1000. However, newly developed HDR displays have a contrast ratio reaching 1:200,000, with the price cost of $49,000.

1.2 The Global and Local Tone Mapping

There are two types of tone mapping algorithm: global (spatially uniform) and local (spatially varying) (Barladian et al., 2004). For global operator, each pixel applies the same transformation, for example; logarithmic function, gamma function, and sigmoid function (see Chapter 2). Global tone mapping algorithm applies the same function to all the pixels. Consequently, these global algorithms tend to preserve the subjective perception of the scene. They have the advantage of being fast and simple which makes them suitable for camera or video processing. However, global tone mapping algorithm will cost the lost of image detail information. (Venkata Lakshmi et al., 2012)

Local tone mapping operator applies a different scale to different parts of an image. Different parts of the image will have different results which depend on the pixel position and on the surrounding pixel value. These methods makes the local operator-based methods provide more details of the image than those global operator based methods. However, they may also cause “halo” effects or ringing artifacts in the reproduction.

When the dynamic range of the scene is approximate or lower than the output display device, it is better to use global tone mapping. If the dynamic range of the scene is far higher than the output display device, it is advised to use the global tone mapping to compress the overall dynamic range of the HDR image. After the compression, the image in this stage may lose a lot of contrast and detail of visibility. Thus, the local tone mapping must be implemented to reproduce the detail and increase the local contrast after the global tone mapping.

Recently, market starts to launch some monitors or televisions whose dynamic range is close to that encountered in the real world. These types of HDR devices make those HDR images able to display without much compression. As a result, new tone mapping technique should be developed for rending of LDR, SDR and HDR scenes to these displays. Moreover, for those images that had already tone-mapped before this to suite the SDR display device, there is a need to re-tone map them to the latest HDR display device. This can be done by reverse the operation of the tone mapping.

1.3 Problem Statement

The wide range of luminance available in high dynamic range images and videos offers a high accuracy representation of natural scenes. However, the existing display devices are insufficient to directly depict the exact contents. There are a lot of industry field that really need high accuracy and visibility for images e.g. Medical and Security Purpose. Therefore a tone mapping algorithm is required to compress the wide range of luminance to display the reduced wide range of luminance of HDR data in order to match the devices' capabilities. The dramatically reduction often reduce the quality of the original quality of HDR contents. For that reason a successful tone mapping algorithm should produce a LDR image which mimic the original scene of a HDR image with high accuracy and at a minimal quality side effect.

1.4 Project Overview

In this thesis, we concentrate on the tone mapping of the HDR scene, i.e. scenes with very wide luminance ratios. The HDR scene is normally of sunny outdoor scenes or a view of indoor room with visible scene outside the window. These HDR scenes are always facing difficulty to be displayed on SDR or LDR display devices since their dynamic range is far higher than the display devices. As a result, a local tone mapping algorithm needs to be introduced to increase the contrast and reduce the loss of visual visibility caused by global tone mapping.

1.5 Scope of Work

A local tone mapping method based on the modified contrast limited adaptive histogram equalization (CLAHE) method which was originally developed for medical imaging is used to render the HDR images to SDR displays. CLAHE has effectively expanded the full dynamic range of display. Then, CLAHE method was extended to become a new local tone mapping algorithm.

The tone mapping algorithm introduced was first compressed using global tone mapping method. Then the image was segmented into smaller regions using region splitting and merging. Next, morphological operation of opening and closing were used to process the mask in order to apply the modified CLAHE in different mask. After that is to decide every mask's parameter clip limit. This step alleviates the artifacts introduced by the original CLAHE algorithm. The original CLAHE have only one clip limit and applied to each tile. The modified CLAHE method applied different clip limit in different mask in order to expand the dynamic range of the image. Software Matlab had been used to develop the algorithms of the propose method. For performance evaluation, a subjective evaluation and an objective evaluation are introduced. The subjective evaluation is conducted by compare the proposed tone mapping operator with Drago, Reinhard and Ward tone mapping algorithms. For objective evaluation, Ward (Larson et al., 1997) and proposed tone mapping algorithm was compared with a reference scene (HDR image) with HDR Visual Difference Predictor by Rafal Mantiuk. HDR VDP can predict whether differences between two images are visible to the human observer or not by generate probability map. The detection map shows how likely HVS will notice a difference between two images. Such metrics are used for testing either visibility of information or visibility of noise. The two generated probability maps was then compared to show is there any improvement of proposed tone mapping algorithm with Ward's tone mapping algorithm. This is due to the proposed tone mapping algorithm was the improved version of the Ward’s tone mapping. The results shows that the proposed tone mapping algorithm has successfully preserved the HDR image local contrast and detail.

1.6 Objectives

This research is to design a tone mapping operator that achieves the following objectives:

- To design and develop a local tone mapping algorithm to reproduce high dynamic range image that match the display device.
- To design and develop a fully automatic tone mapping algorithm without deciding any input parameter.
- To conduct an assessment to compare the images processed by proposed tone mapping algorithm with other well known tone mapping operators.

1.7 Thesis Contribution

The key contribution of this thesis is the development of a modified algorithm of CLAHE. CLAHE which was originally developed for medical imaging used one clip limit value and apply to each tile to enhance the picture. In this thesis, a modified CLAHE algorithm was applied to expand the dynamic range of the image after the global tone mapping. The modified CLAHE used morphological operation of opening and closing to segment the image into smaller regions. Then, the smaller regions used different clip limit value to increase the local contrast of each region.

1.8 Thesis Organization

The thesis contains 5 chapters. **Chapter 1** introduces an overall view of tone mapping study. It addresses the research background, the purpose and objectives of the work. Thesis organization is presented in the end of this chapter.

Chapter 2 reviews the global and local tone mapping methods. The basic global tone mapping algorithms is described and some of the local tones mapping techniques are discussed. The histogram equalization and CLAHE are also introduced and lastly the tone mapping operator that based on histogram equalization is reviewed.

Chapter 3 presents the CLAHE-based local tone mapping method that we developed to render HDR images to LDR displays. We first present the treatment of the luminance channel that includes a global tone mapping processing followed by a local processing based on CLAHE. The local processing uses region splitting and merging to segment the image into smaller part and applied different clip limit at different mask.

Chapter 4 presents the results and discussions. An assessment was conducted to the fifteen images that had been processed by proposed tone mapping operator. Comparison has also been made to the Reinhard's, Drago's and Ward's tone mapping operator and the result was discussed.

Chapter 5 presents the conclusions and future works. The summary of the research is given and future work of the research is discussed.

1.9 Conclusion

The existing display devices in the market nowadays are insufficient to directly depict the exact contents for HDR images. Therefore a tone mapping algorithm is required to compress the wide range of luminance to display the reduced wide range of luminance of HDR data to match the devices' capabilities. In this chapter, general information of why tone mapping process is important was addressed out. The objectives and contribution of the proposed tone mapping were carried out.

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