Single Image HDR Imaging Method based on Retinex Theory

03CS6902 Mini Project

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student, for the course work in **03CS6902 Mini Project**, under our guidance and supervision, in partial fulfillment of the requirements for the award of the degree, M. Tech. Computer Science & Engineering (Image Processing) of **APJ Abdul Kalam Technological University**.

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Shanu Joy

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Abstract

This project is an attempt to enhance uneven illuminations in images by generating and fusing multi-level illuminations from a single image. Image degradation is said to occur when a certain image undergoes loss of stored information either due to digitization or due to decreasing visual quality. One of the major cause of image degradation is due to uneven lighting conditions, like low light or over exposure conditions. Images obtained under the low light conditions such as night-time, underwater and medical images and overly exposed conditions undergoes information loss and results in degradation. Implementation of this project focus on developing a modified single image HDR imaging method which is based on the retinex filtering scheme for the purpose of enhancing such kind of images. Requirements for the implementation of project are covered from a practical approach. Block diagrams for explaining work flow of the project are used to demonstrate each modules in the project.

Contents

Chapter 1

Introduction

A variety of image enhancement methods have been proposed for improving the quality of images captured in uneven illumination conditions. Earlier, single image high dynamic range (HDR) imaging method [3] was developed which mimic the process of original HDR imaging technique. It first generates multiple images with different exposure from a single input image and then produce larger bit depth images by combining them or produce tone-mapped-like images by adding them with appropriate weights. This method only deal with the illumination components of the image and not with reflectance components. Since luminance(L) (light that reaches the eye) is a function of both illumination(I) (light source) and the percentage of that illumination that is reflected off the surface (reflectance(R))(L= I*R), both I and R components are needed to be enhanced in order to enhance the image. This concept is explained in Retinex Theory [10].
Retinex [10] is a concept of capturing an image in such a way in which a human being perceives it after looking at an object at the place with the help of their retina (Human Eye) and cortex (Mind). On the basis of Retinex theory, an image is considered as a product of illumination and reflectance from the object. Retinex focuses on dynamic range and color constancy of an image. Existing single image high dynamic range (HDR) imaging method can be modified by the application of retinex theory.

1.1 Proposed Project

This project focuses on developing a new single image HDR imaging method based on the concept of Retinex theory [10] i.e., here both illumination and reflectance components of the image are estimated and then processed them separately. It also enhances the overall image by generating pseudo multi-exposure illuminations and combining them in the manner of exposure fusion. This project is implemented in different steps like Decompostion stage, Selective reflectance scaling (SRS), Virtual illumination generation (VIG), Luminance reproduction and weight maps for synthesis techiques.

1.1.1 Problem Statement

This project aims at enhancing uneven illuminations in Low Dynamic Range (LDR) images by using a modified single image HDR imaging method based on the concept of Retinex theory.

1.1.2 Proposed Solution

Implementation of proposed project is carried out in different steps. Image decomposition stage decomposes luminance into illumination and reflectance components. For this purpose, this stage uses weighted least square filter (WLSF) which consumes more run time during implementation. So this can be modified by using guided filter[4] which is also an edge preserving and smoothing filter like WLSF. Among them, guided filter is the fastest one as it has a fast and non approximate linear time algorithm, regardless of the kernel size and the intensity range. Thus run time complexity can be reduced. Processing of both illumination and reflectance components are performed separately by using Selective Reflectance Scaling (SRS) and Virtual illumination generation (VIG) methods. Finally luminance reproduction and weight map for synthesis technique is performed to generate final enhanced image.

Appropriate weight rule is needed to blend the pseudo multi-exposure luminances as an illumination-equalized single luminance. Weight rule prescribed in the base paper are modified to obtain sufficiently required equalized output.

Chapter 2

Report of Preparatory Work

There are several approaches to enhance unevenly illuminated images. Some of them are retinex based ilumination adjustment method [5], single image based method [6], enhancement based on retinex theory approach [7, 8] and single image enhancement based on retinex approach [9]. Related works on these approaches are reviewed in this section.

2.1 Literature Survey Report

1. Guo, X., Li, Y. and Ling, H.: **"LIME: Low-light image enhancement via illumination map estimation"** [5]: IEEE Transactions on image processing, vol.26, no.2, pp.982-993, 2016.

   LIME is based on retinex-based illumination adjustment approach which intends to enhance a low-light image by estimating its illumination map. This method only estimates illumination without obtaining reflectance which shrinks the solution space and reduces the computational cost to reach the desired result. Illumination of each pixel is first estimated individually by finding the maximum value in R, G and B channels. Then, it exploits the structure of this illumination to refine the illumination map. Having the well constructed illumination map, enhancement can be achieved accordingly. An Augmented Lagrangian Multiplier (ALM) based algorithm is applied to exactly solve the refinement problem. Thus it requires a non-linear operation to resize and adjust the enhanced illumination map. This extra post-processing steps reduced the strength of this model, and the enhanced results often suffered from color distortion. Another speed-up solver is designed to intensively reduce its computational load.

2. Huo, Y. and Zhang, X.: **"Single image-based HDR image generation with camera response function estimation"** [6]: IET Image Processing, vol.11, no.12, pp.1317-1324, 2017.

   This method proposed a single-image-based method to generate HDR images based on camera response function (CRF) reconstruction. The method first estimates the CRF according to the empirical model and the input LDR image. Then, the empirical model of the inverse CRF is constructed according to the relationship between the derivatives of CRF and its inverse function; the optimal solution of inverse CRF is obtained depending on the imaging properties of the edge pixels. Finally, the HDR image is generated by performing the inverse

CRF on the original LDR image. The imitation of imaging procedure inherently makes the final HDR image high quality.

3. Park, S., Yu, S., Moon, B.: Ko, S. and Paik, J.: **"Low-light image enhancement using variational optimization-based retinex model"** [7]: IEEE Transactions on Consumer Electronics, vol.63, no.2, pp.178-184, 2017.

   This method performs low-light image enhancement based on retinex theory approach. It first estimates the initial illumination and uses its gamma corrected version to constrain the illumination component. Then variational-based minimization is iteratively performed to separate the reflectance and illumination components. Color assignment of the estimated reflectance component is then performed to restore the color component using the input RGB color channels. It assumes that the images already contain a good representation of the scene content and they are noise- and color distortion-free images.

4. Li, M., Liu, J., Yang, W.: Sun, X. and Guo, Z.: **"Structure-revealing low-light image enhancement via robust retinex model"** [8]: IEEE Transactions on Image Processing, vol.27, no.6, pp.2828-2841, 2018.

   This method is the continuation of LIME [5] where initial illumination of each pixel is estimated by individually finding the maximum values in three color channels (Red, Green and Blue). Then, a structure-aware smoothing model that is developed to refine the initial illumination component is applied to obtain the sophisticated illumination. For the reflectance component, a denoising technique is employed to suppress possible noise in dark areas. Finally, it reproduced an improved image by combining the adjusted illumination and the denoised reflectance.

5. Cai, J., Gu, S. and Zhang, L.: **"Learning a deep single image contrast enhancer from multi-exposure images"** [9]: IEEE Transactions on Image Processing, vol.27, no.4, pp.2049-2062, 2018.

   This method proposed a single image enhancement based on retinex approach which mainly focuses on Single Image Contrast Enhancement (SICE), which is aimed at a problem of low contrast under underexposure and overexposure. Its main contribution is to build a multi-exposure image data set, including low-contrast images with different exposures and corresponding high-quality reference images. A two-stage enhancement model is proposed. In the first stage, the weighted least squares filtering (WLSF) method is used to decompose the original image into low-frequency components and high-frequency components, and then the two components are enhanced separately. This decomposition step uses the traditional method, and the Retinex Net for the proper decomposition of its components. n the second stage, the enhanced low-frequency and high-frequency components are merged, and then enhanced again and output the result. This two-stage structure is designed completely avoid the phenomenon of color cast.

6. Jae Sung Park, Jae Woong Soh, and Nam Ik Cho: **"Generation of high dynamic range illumination from a single image for the enhancement of undesirably illuminated images"**[1] : Multimedia Tools and Applications, vol.78, no.14, pp.20263–20283, February 2019.

   This method proposed a single image HDR imaging method based on retinex filtering. It decomposes image into illumination and reflectance components and process them separately. Weighted Least square filter (WLSF) is used for decomposing image. To blend pseudo multi-exposure luminance as an illumination-equalized single luminance, appropriate weighting rule is designed. Finally, obtains an illumination-equalized luminance by applying the conventional weighted-averaging equation. This result is then tone mapped to obtain final output.

2.2 System Study Report

Image degradation is said to occur when a certain image undergoes loss of stored information either due to digitization or conversion (i.e algortithmic operations) or due to decreasing visual quality. One of the major cause of image degradation is due to undesirable lighting conditions, like low light or over exposure conditions. Low light results in capturing images which contains only lower sub range of intensities. Similarly over exposure conditions results in images with only brighter sub range of intensities. This will lead to the generation of low dynamic range (LDR) images. To improve the quality of LDR images captured in uneven illumination conditions and to restore the lost information, image enhancement is needed to be performed.

Increasing the dynamic range of a single low dynamic range (LDR) image and converting it to High Dynamic Range (HDR) is considered as an essential step for the enhancement of degraded images. This project focuses on developing a new single image HDR imaging method based on the concept of retinex theory i.e., both the illumination and reflectance components of LDR image is processed seperately to produce pseudo multi-exposure images, and then final enhanced image is obtained by using a multi-exposures fusion algorithm. Generating an HDR image from a single exposure image is called a single image HDR imaging method. This is more efficient and time saving than original HDR imaging technique which requires to capture multiple images with different exposures for the generation of HDR image.

Chapter 3

Project Design

3.1 Project Design

Main aim of this project is to design a simple and effective method for enhancing the estimated reflectance and illumination, and also to further enhance the overall image by generating pseudo multi-exposure illuminations and combining them in the manner of exposure fusion. The most important and sophisticated process in this algorithm is to generate multiple illuminations that correspond to the multiple LDR images of different exposures for HDR imaging, without any prior information (capture device, exposure conditions etc.) on the input images.
Different processes included in this work are extraction of luminance from RGB and its decomposition to illumination and reflectance, Virtual Illumination Generation, Selective Reflectance Scaling, luminance reproduction and weight map synthesis, and finally applying tone reproduction to obtain enhanced image.

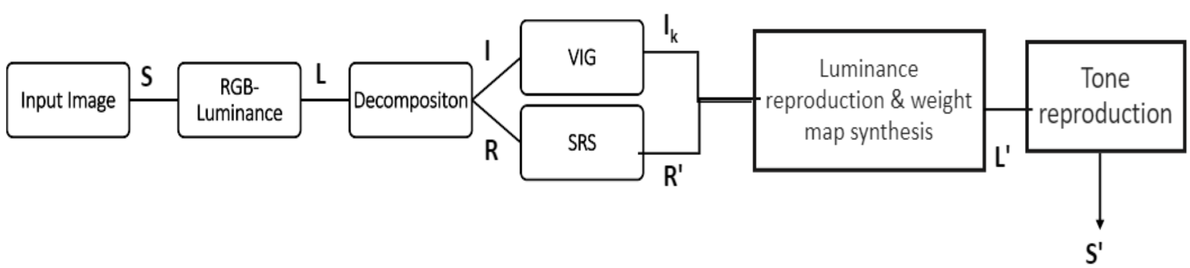

Figure 3.1: Block diagram of proposed method

3.1.1 Image decomposition

This proposed enhancement algorithm starts with the Retinex-based illumination and reflectance decomposition.

The luminance(L) is first obtained from the input RGB image using RGB to luminanance conversion. Illumination component is then obtained by the filtering of L with a filter G which is an

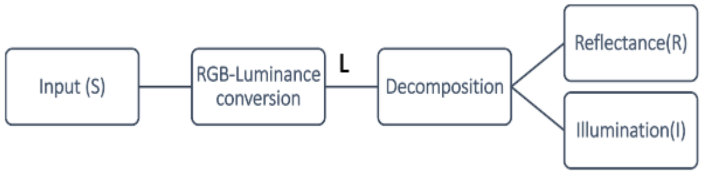

Figure 3.1.2: Block diagram of decomposition stage

edge preserving and smoothing filter called Guided filter.

$$I = (L * G()) \tag{3.1}$$

Finally reflectance information is obtained by the difference between the input luminance and the estimated illumination.

$$R(i,j) = log(L(i,j)) - log(I(i,j)) \tag{3.2}$$

3.1.2 Selective reflectance scaling (SRS)

Selective Reflectance Scaling (SRS) method is used to enhances the details in relatively bright areas. In case of bright areas, increasing the illumination may saturate the pixel values. Also, sharpness or details cannot be sufficiently enhanced in relatively well-illuminated areas because illumination equalization method is not pixel-wise processing. For these reasons, instead of adjusting the illumination, SRS method stretches the reflectance at bright areas where the illumination component is larger than a certain threshold.

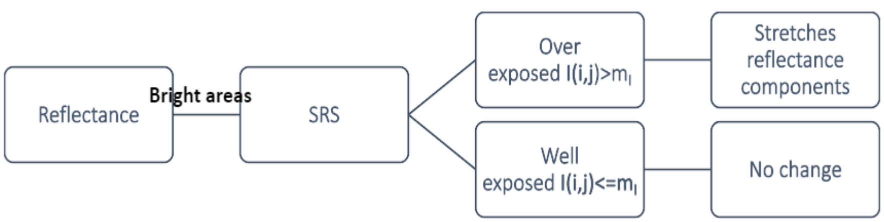

Figure 3.1.3: Block diagram of SRS stage

Reflectance is modified according to the equation (2.3) where m_I is the average value of the estimated illumination and the parameter γ R is the gamma value which is set to 0.5

$$R'(i,j) = \begin{cases} R(i,j)\left(I(i,j)/m_I\right)^{\gamma R} & , I(i,j) > m_I \\ R(i,j) & , otherwise \end{cases} \tag{3.3}$$

By stretching the reflectance components of over exposed region, details in bright areas become clearer than before. The reason why SRS algorithm is not applied to dark areas is that it can amplify the noise in those areas. Hence the dark areas are improved by the illumination fusion method called VIG.

3.1.3 Virtual illumination generation (VIG)

As SRS corrects reflectance components of the image, illumination components are simultaneously processed using VIG method.
Illuminations are adjusted separately for both dark and bright areas in the image. For this locally different adjustment strategy, two maps that represent the brightness/darkness of the illumination intensities are defined. Specifically, the first map is named as the brightness map (BM) which is the image of normalized illumination intensity, and the second is the darkness map (DM) which contains the inverse of illumination at each pixel position. Since bright areas are corrected using SRS method, VIG is only applied to darkness map(DM).

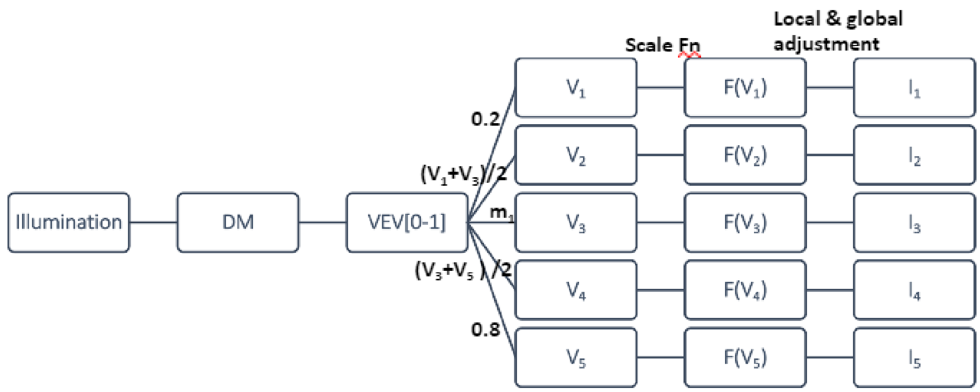

Figure 3.1.4: Block diagram of VIG stage

With a single illumination I and with unknown exposure value (EV), VIG designs a simple and effective algorithm that generates multiple virtual illuminations. Steps performed are applying virtual exposure value, scale function and local and global adjustment.

1. Virtual Exposure Value (VEV)

   Virtual exposure value (VEV) is the average of normalized illumination in the range of [0,1]. In this experiment, this method generate four different illuminations that correspond to different VEVs, so that we have five illuminations including the original (VEV= m_I) where m_I is the average value of the estimated illumination. Specifically, it defines five v_k (k = 1, 2, 3, 4, 5) where $v_3 = m_I$, $v_3 = 0.2$, $v_5 = 0.8$, $v_2 = (v_1 + v_3)/2$, and v4 = (v3 + v5)/2. v_1 to v_5 correspond to the darkest, darker, original, brighter, brightest images. If m_I is less than 0.2 or larger than 0.8, then it means that most part of original image is saturated and thus we give up the enhancement.

2. Applying scale function

   After obtaining multiple virtual illuminations, a scale function is applied to them that maps a VEV to a scale factor, where the range of scale factor is adjusted according to the overall illumination. Here scale function is in the form of sigmoid. Specifically, it is defined as eqn(2.4) where V is the VEV in the range of [0,1], m_I is the average of the normalized illumination of original image, σ_s is the smoothness factor of the sigmoid curve which is just set to 1 in all of our experiments, and r is the adaptive amplitude which controls the range of the scale function.

$$F(V) = r\left(\frac{1}{1+e^{-\sigma_s(v-m_I)}} - \frac{1}{2}\right) \tag{3.4}$$

3. Local and global adjustment

Illumination obtained after applying scale function is globally adjusted according to the scale factor, and then locally adjusted depending on the local brightness. This is implemented by using combined global and local adjustment equation. Global adjustment is to multiply $F(V_k)$ to the original illumination and add it to the original.

$$I_k(i,j) = (1 + F(V_k))I(i,j) \tag{3.5}$$

Local adjustment is added to the above equation for boosting the illumination change at dark areas. This is implemented as,

$$I_k(i,j) = (1 + F(V_k))I(i,j) + F(V_k)I'(i,j) \tag{3.6}$$

where I' is the inverse of the normalized initial illumination I, i.e., dark map(DM). Since the DM is large at the dark areas, the (2.6) can enlarge the change of illumination more than the (2.5) at the dark areas.
Thus combined local and global adjustment equation (2.6), is applied to each $F(V_k)$ where k=1,2,3,4,5 and thus generates a set of multiple illuminations I_k which correspond to the ones in multi-exposure HDR imaging techniques.

3.1.4 Luminance reproduction and weight maps for synthesis

The next step is to generate pseudo multi-exposure luminances from the enhanced reflectance R'(eqn 2.3) and I_k(eqn 2.6). For this first obtain the luminance image for each E_v as,

$$L_k(i,j) = exp(R'(i,j))I_k(i,j) \tag{3.7}$$

To blend the pseudo multi-exposure luminances from eqn (2.7) as an illumination-equalized single luminance, first design an appropriate weighting rule. This weight rule is designed separately for under and over exposed area.

Under-exposed luminance: Bright areas need to be stretched. for this, take all the details in the brightest areas by setting the weights in these areas larger than others. This can be simply implemented by setting the weight map as the normalized illumination values.

Over-exposed luminance: Dark areas are needed to be stretched. For this, take all the details in the dark areas. Hence, let the weighting values in the dark area be larger than those in other regions. This is achieved by setting the weight map as the inverse of normalized illumination. The weight maps are represented as,

$$w_k = \begin{cases} \frac{I_k}{max(I_k)} & k = 1,2,3 \\ 1 - \frac{I_k}{max(I_k)} & k = 4,5 \end{cases} \tag{3.8}$$

where I_k is the normalized illumination.

Finally, obtain an illumination-equalized luminance by applying the conventional weighted-averaging as,

$$L'(i,j) = \frac{\sum_{k=1}^{N} L_k(i,j) w_k(i,j)}{\sum_{k=1}^{N} w_k(i,j)} \tag{3.9}$$

Here L' represents the final luminance image and w_k is the blending weight map for the k-th luminance image.
By adopting tone reproduction process for the final luminance image, brightness and detail-enhanced image (S') is obtained.

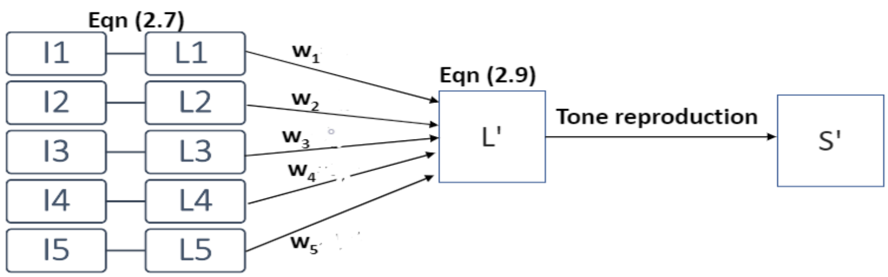

Figure 3.1.5: Block diagram of luminanace reproduction stage

3.2 Hardware & Software Requirements

Dataset	:	Collected publicly available dataset
Operating System	:	Any Operating System
Supporting software	:	Python
Processor	:	Intel Core i5 7th Gen 2.50GHz
RAM	:	4GB

Chapter 4

Implementation

The four stages of implementation of this project are:

1. Image decomposition
2. Selective reflectance scaling (SRS)
3. Virtual illumination generation (VIG)
4. Luminance reproduction and weight maps for synthesis

4.1 Image decomposition

This algorithm starts with the Retinex-based illumination and reflectance decomposition. It consist of two steps. At first, an RGB input image is converted to gray scale using an openCV inbuilt function called cv2.cvtColor(). Then guided filter is applied using gdft(img, r) function, to obtain illumination components from image. In the second step, Reflectance information is obtained by taking the difference between the input luminance and the estimated illumination.

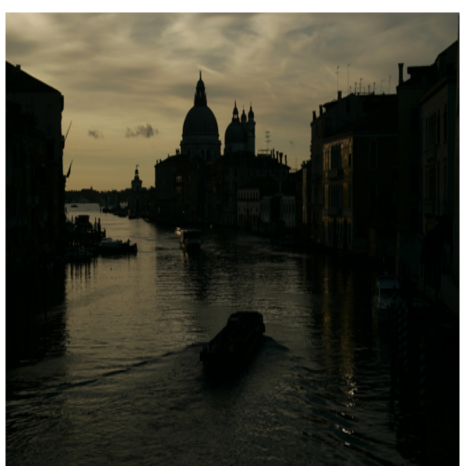

Figure 4.1.1: Input Image

(a) Illumination(I)

(b) Reflectance(R)

4.2 Selective reflectance scaling (SRS)

In order to process reflectance information, SRS method is applied. It performs scaling operation on some selected reflectance. This method is used to enhance the details in relatively bright areas. I.e., if the reflectance value of a pixel is greater than a certain threshold, then it undergoes stretching operation. All other pixel values are kept unchanged. SRS(R, I) function module performs this operation.

Figure 4.2.1: SRS

4.3 Virtual illumination generation (VIG)

In this method, illuminations are processed using 3 steps. At first, it takes darkness map of image. VIG is applied to this darkness map(DM) which contains the inverse of illumination at each pixel position. It is a simple and effective algorithm that generates multiple virtual illuminations I_k. This set of I_k corresponds to the multi-exposure LDR images which original HDR imaging method takes by using time-division or space-division multiple acquisition. No prior information about capture device, exposure conditions etc. on the input images is available. With a single illumination I and with unknown exposure value (EV), VIG generates multiple virtual illuminations. Then to each illuminations, a scale function is applied as second step then in final step, local and global adjustment is applied to each.

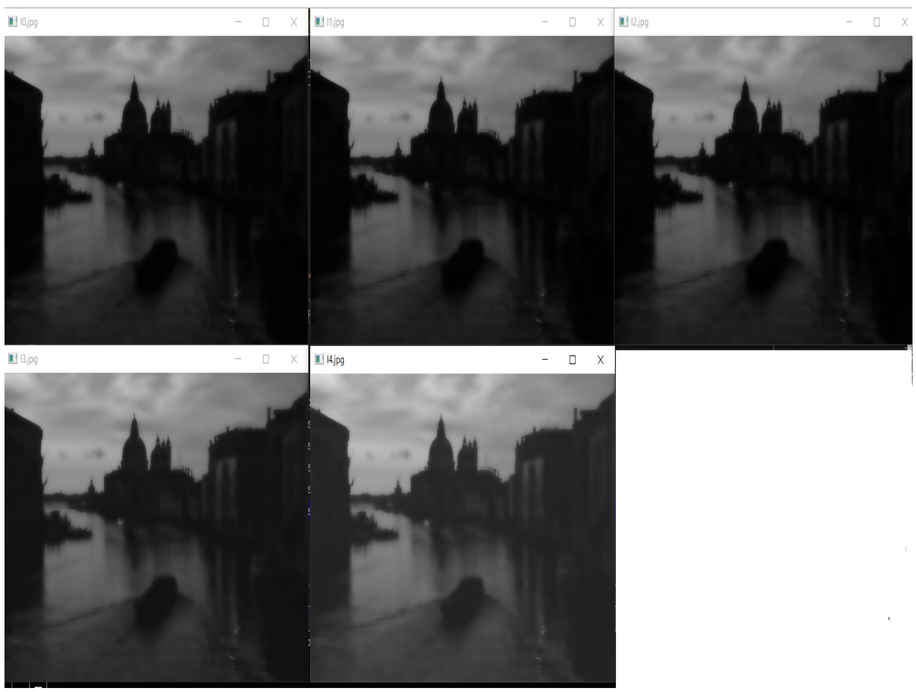

Figure 4.3.1: 5 virtual illuminations

4.4 Luminance reproduction and weight maps for synthesis

It generates pseudo multi-exposure luminance from the enhanced reflectance R' and I_k. To blend this pseudo multi-exposure luminance as an illumination-equalized single luminance, appropriate weighting rule is designed. This weight rule is designed separately for under and over exposed luminance area. Finally, obtains an illumination-equalized luminance by applying the conventional weighted-averaging equation.

Figure 4.4.1: Illuminations equalized luminance

By adopting tone reproduction process for the final luminance image, brightness and detail-enhanced image (S') is obtained.

Figure 4.4.2: Final tone reproduced output

Chapter 5

Results & Conclusions

5.1 Results

(a) Input

(b) Output

5.2 Conclusions

This project focus on developing a new single image HDR imaging method based on the concept of Retinex theory. Generating an HDR image from a single exposure image is called a Single image HDR Imaging method. On the basis of Retinex theory, an image is considered as a product of illumination and reflectance from the object. Existing single image high dynamic range (HDR) imaging method can be modified by the application of this retinex theory. For obtaining working and structure of this method, I referred a base paper called generation of high dynamic range illumination from a single image for the enhancement of undesirably illuminated images[1]. Modifications conducted in this referred method are

1. Filter used in decomposition stage for this method was weighted least square (WLSF). But run time taken for obtaining output was high. So for reducing run time complexity another edge preserving and smoothing fiter called Guided filter was used. Guided filter is the fastest

one as it has a fast and non approximate linear time algorithm, regardless of the kernel size and the intensity range. Thus run time complexity can be reduced.

2. Appropriate weight rule is needed to blend the pseudo multi-exposure luminances as an illumination-equalized single luminance. Weight rule prescribed in the base paper are changed to obtain sufficiently required equalized output.

For the evaluation, a publicly available dataset called IQA [11] is used. Most of the Final ouputs obtained are more clearer than the input image. This method helps to reduce image degradation effects and to recover the informations present in the image.

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