Single Image HDR Imaging Method based on Retinex Filtering

03CS6902 Mini Project
Design Report

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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 [1].

1.1 Proposed Project

This project aims at developing a modified single image HDR imaging method which is based on the retinex filtering scheme.

1.1.1 Problem Statement

This project is an attempt to enhance uneven illuminations in images by generating and fusing multi-level illuminations from a single image. This work proposes a new single image HDR imaging method based on the Retinex filtering scheme [2] i.e., here both illumination and reflectance components of the image are estimated and then processed them separately.

1.1.2 Proposed Solution

This proposed algorithm is based on the single HDR approach. By increasing and decreasing the illumination to several levels, it generate several illumination images which correspond to different camera exposure values. Multiplication of these illuminations to the reflectance produces pseudo multi-exposure images, and then finally obtain the enhanced image by using a multi-exposures fusion algorithm.

Chapter 2

Project Design

2.1 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.

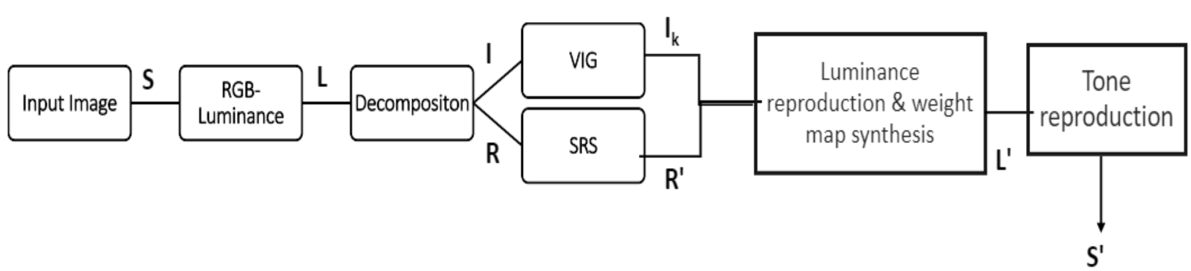

Figure 2.1.1: Block diagram of proposed method

2.1.1 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

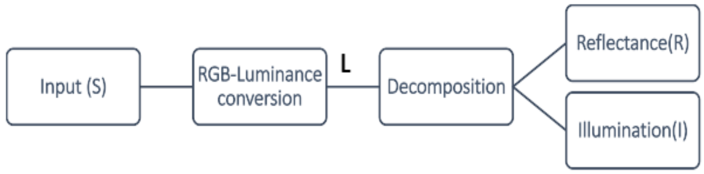

Figure 2.1.2: Block diagram of decomposition stage

usually a normalized Gaussian function.

$$I = (L * G()) \tag{2.1}$$

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

$$R(i,j) = log(L(i,j)) - log(I(i,j)) \tag{2.2}$$

2.1.2 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.

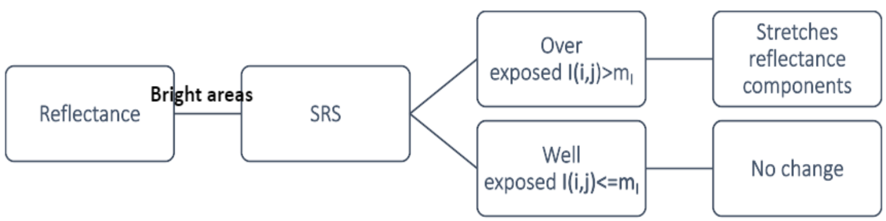

Figure 2.1.3: Block diagram of SRS stage

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

$$R'(i,j) = \begin{cases} R(i,j)\Big(I(i,j)/m_I\Big)^{\gamma R} & , I(i,j) > m_I \\ R(i,j) & , otherwise \end{cases} \tag{2.3}$$

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.

2.1.3 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).

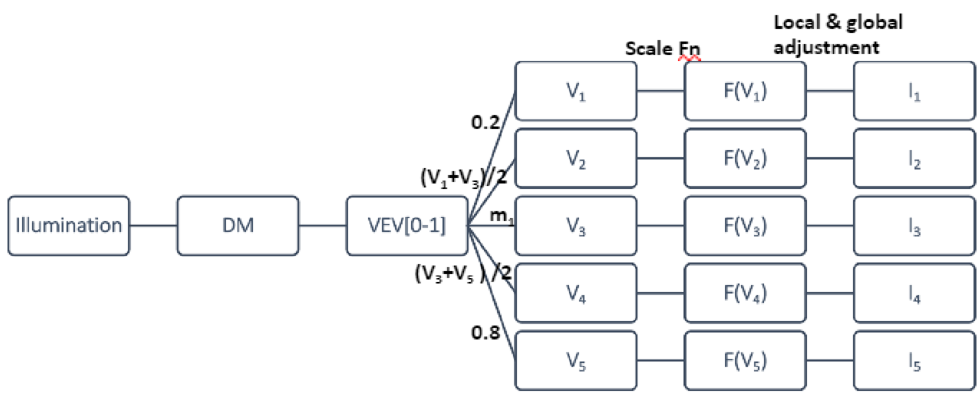

Figure 2.1.4: Block diagram of VIG stage

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.

$$F(V) = r\left(\frac{1}{1+e^{-\sigma_s(v-m_I)}} - \frac{1}{2}\right) \tag{2.4}$$

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.

$$I_k(i,j) = (1 + F(V_k))I(i,j) \tag{2.5}$$

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

$$I_k(i,j) = (1 + F(V_k))I(i,j) + F(V_k)I'(i,j) \tag{2.6}$$

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.

2.1.4 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,

$$L_k(i,j) = exp(R'(i,j))I_k(i,j) \tag{2.7}$$

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,

$$w_k = \begin{cases} I_k & k = 1,2,3 \\ I_k^{-1} & k = 4,5 \end{cases} \tag{2.8}$$

where I_k is the normalized illumination, and I_k^{-1} means that each value in the illumination is inversed.
Finally, obtain an illumination-equalized luminance by applying the conventional weighted-averaging as,

$$L'(i,j) = \frac{\sum_{k=1}^{N} L_k(i,j) w_k(i,j)}{\sum_{k=1}^{N} w_k(i,j)} \tag{2.9}$$

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.

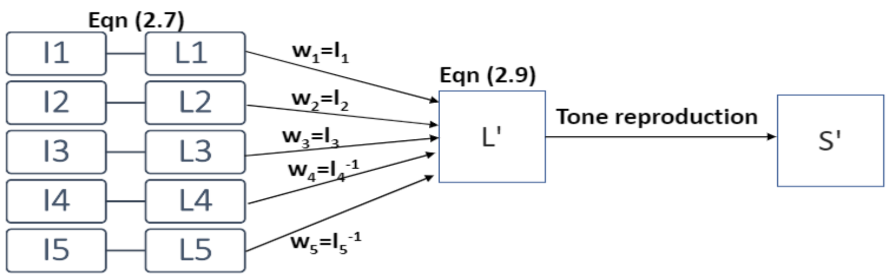

Figure 2.1.5: Block diagram of luminanace reproduction stage

2.2 Hardware & Software Requirements

Operating System	:	Any Operating System
Supporting software	:	Python, Opencv, Numpy, scipy
Processor	:	Intel Core i5 7th Gen 2.50GHz
RAM	:	4GB

Chapter 3

Project Progress

Details of the work done so far.

1. Studied the reference paper.
2. Conducted literature review on related journals
3. Studied methods used in the project and made block diagrams for each module
4. Installed Python and started learning it.
5. Collected some data sets.
6. Made the design of the project.

3.1 Work Schedule

1. Work assigned for the period (26/04/2021) to (01/05/2021)
   Identify suitable project area
2. Work assigned for the period (02/05/2021) to (11/05/2021)
   Analyse various project topics and related journals based on the selected domain
3. Work assigned for the period (12/05/2021) to (22/05/2021)
   Study the reference paper.
4. Work assigned for the period (23/05/2021) to (31/05/2021)
   Prepare for IC and choose a guide
5. Work assigned for the period (01/06/2021) to (10/06/2021)
   Check for other papers related to this topic.
   Conduct literature review on project topic.
6. Work assigned for the period (11/06/2021) to (21/06/2021)
   Study different methods used in the project and prepare its algorithm/block diagram.
7. Work assigned for the period (22/06/2021) to (28/06/2021)
   Install Python and start learning it.

8. Work assigned for the period (23/07/2021) to (31/07/2021)
   Collect data sets for the project and install other required python packages.

9. Work assigned for the period (01/08/2021) to (10/08/2021)
   Start working on different project modules and Make the design of the project.

10. Work assigned for the period (11/08/2021) to (24/08/2021)
    Prepare for design presentation.

11. Work assigned for the period (25/08/2021) to (31/08/2021)
    Design presentation
    Obtain approval to start implementation.
    Start the implementation.

12. Work assigned for the period (01/09/2021) to (10/09/2021)
    Complete the implementation of each modules.

    (a) Perform RGB to Luminance conversion and decomposition of luminanace
    (b) Implementation of SRS module
    (c) Implementation of VIG module
    (d) Determining weight map from illumination component itself and reproducing luminance
    (e) Implementation of tone reproduction module to obtain enhanced image.

13. Work assigned for the period (11/09/2021) to (21/09/2021)
    Complete the entire coding part and test it to analyse its performance.
    Prepare for final presentation

References

[1] 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: Multimedia Tools and Applications, 78(14): 20263–20283, February 2019.

[2] Li, Mading, Jiaying Liu, Wenhan Yang, Xiaoyan Sun, and Zongming Guo: Structure-revealing low-light image enhancement via robust retinex model: IEEE Transactions on Image Processing, 27(6): 2828-2841, 2018.

[3] Huo, Y. and Zhang, X: Single image-based HDR image generation with camera response function estimation: IET Image Processing, 11(12): 1317-1324, 2017.