A PROJECT REPORT
ON

LOW LIGHT IMAGE ENHANCEMENT BASED ON CAMERA RESPONSE MODEL

Submitted in partial fulfillment of the Requirement for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

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Affiliated to J.N.T.U.A - Anantapuramu, Approved by A.I.C.T.E., New Delhi,

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Year: 2019-2023

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CERTIFICATE

This is to certify that the dissertation entitled "LOW LIGHT IMAGE ENHANCEMENT BASED ON CAMERA RESPONSE MODEL" that is being submitted by S. AFRIN (20095A0401), J. SAI HEMANTH(19091A04G0), Y.VINAY KUMAR (19091A04R5), G.GANGA SARITHA (19091A0445) under the esteemed guidance of Dr. J. SOFIA PRIYA DHARSHINI, **Associate Professor of ECE for project of the award of B.Tech, Degree in ELECTRONICS AND COMMUNICATION ENGINEERING in the RAJEEV GANDHI MEMORIAL COLLEGE OF ENGINEERING AND TECHNOLOGY, Nandyal (Affiliated to J.N.T.U.A Anantapuramu) is a record of bonafide work carried out by them under your guidance and supervision.**

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CANDIDATE'S DECLARATION

We hereby declare that the work done in this Project titled "**LOW LIGHT IMAGE ENHANCEMENT BASED ON CMAERA RESPONSE MODEL**" submitted towards completion of main project in IV Year II Semester of B. Tech (ECE) at the **Rajeev Gandhi Memorial College of Engineering & Technology**, Nandyal. It is an authentic record of our original work done under the guidance of **DR. J. SOFIA PRIYA DARSHINI,Associate professor** Dept. of ECE, RGMCET, Nandyal. We have not submitted the matter embodied in this project for the award of any other Degree in any other institutions.

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ABSTRACT

The exponential increase in the dependence of technological growth on the captured images makes it necessary for the images taken even in lowlight conditions to bring forth the hidden details and make the images appear more visually impressive. These low-light images not only present uncertain outcomes but also pose a threat to the producing hindrance in measurement and tracking tasks such as trajectory geometry, object detection, segmentation, and so on. The image details that are hidden in these low-light images present a strong need for suitable image enhancement techniques.

Low-light image enhancement algorithms can improve the visual quality of low-light images and support the extraction of valuable information. The existing methods inevitably include intensity distortions or global enhancements of the image, which cause a loss of local information. In this proposed methodology, we achieved Enhancing the low-light images locally to preserve their details and concurrently adapting camera response models to maintain the naturalness of the image. This methodology introduces an innovative technique to enhance low-light images in order to bring forth the details hidden in it while simultaneously preserving their naturalness in order to make these images appear visually more attractive and scientifically more useful. In this Methodology the amount of information present in an image(DE) is improved by 80% compare to existing methods.

Key Words: Camera response function, Image enhancement, local enhancement, lowlight images measured adaption mode.

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CHAPTER 1
INTRODUCTION

1.1 Image Enhancement

Low-Light Image Enhancement is a computer vision task that involves improving the quality of images captured under low-light conditions. The goal of low-light image enhancement is to make images brighter, clearer, and more visually appealing, without introducing too much noise or distortion. The image enhancement techniques that present in the contemporary world are broadly classified into two categories: global enhancement and local enhancement. Global enhancement performs same processing on all image pixels regardless of their spatial distribution. Linear amplifying is a simple and straight forward global enhancement method.

However, global enhancement may results in detail loss in some local areas because a global processing cannot ensure all local areas be well enhanced. Taking the spatial distribution of pixels into consideration, local enhancement can obtain better results and become the main-stream of recent techniques. Most Retinex- based methods get enhanced results by removing the illumination part while the others keep a portion of the illumination to preserve naturalness. However, those methods may suffer from over and under enhancement due to ignoring the camera response characteristics. To preserve the image naturalness and achieve more accurate enhancement results, in-camera processing needs to be considered when designing enhancement algorithms. The camera response model plays an important role in image enhancement techniques as it provides valuable information about the image formation process. By using the camera response model, we can adjust the image to bring out the hidden details and improve the overall quality of the image. This technique works by estimating the camera response function, which is the relationship between the pixel values of an image and the corresponding scene radiance values.

The camera response function is estimated by analyzing the pixel values of the image captured under different illumination conditions. Once the camera response function is estimated, it is used to map the pixel values of the low light image to the corresponding scene radiance values. This mapping allows us to enhance the image by adjusting the brightness and contrast, reducing noise, and correcting color distortion.

1.2 Problem Statement:

The main challenge in low light image enhancement is that the amount of light available for the camera to capture is limited, resulting in images that are typically darker and noisier than those captured in well-lit environments. This makes it difficult to see details in the image and can lead to misinterpretation or misdiagnosis. However, there are several factors that make this problem complex and challenging, such as:

Non-uniformity of illumination across the image: Images captured under low-light conditions often have non-uniform illumination, which can result in shadows and highlights that make it difficult to see details in certain parts of the image.

Noise and other image artifacts: Images captured in low-light conditions are often noisy, which can reduce the clarity of the image and make it difficult to distinguish between different objects or features in the image.

Complex scene content: Low-light images can contain complex scenes with a wide range of colors, textures, and lighting conditions, making it difficult to enhance the image without introducing artifacts or distorting the image.

Camera response model-based techniques aim to address this challenge by taking advantage of the fact that cameras respond to light in a particular way, and using this information to enhance the captured images.

1.3 Objective:

Low light image enhancement based on camera response model is to improve the visibility and quality of images captured under low-light conditions using information about the camera's response to light. In low light conditions, the amount of light available for the camera to capture is limited, resulting in images that are typically darker and noisier than those captured in well- lit environments. Camera response model-based image enhancement techniques take advantage of the fact that cameras respond to light in a particular way, and use this information to enhance the captured images. Specifically, camera response model-based techniques aim to estimate the response function of the camera, which describes how the camera converts light intensities to pixel values. By using this information, these techniques can effectively adjust the image's brightness and contrast while reducing noise and other image artifacts. The ultimate goal of low light image enhancement is to improve the visibility and quality of the images captured under low-light conditions, making it easier to see details and obtain useful information from the images. This can be especially important in fields such as security, surveillance, and medical imaging, where clear and accurate images are critical for making informed decisions.

1.4 Organization of thesis:

The organization of the thesis for low light image enhancement based on camera response model can be structured as follows:

Introduction: This chapter will provide an overview of the problem statement and objective of the thesis. It will also provide an introduction to low light images and the need for enhancement techniques.

Basics of digital image processing: This chapter will provide an overview of the concepts of image processing. It will also provide fundamental steps in image processing and applications of image processing.

Literature review: This chapter will review the existing literature on image enhancement techniques, including retinex methods, PCA using reflection model, estimation of illumination reflectance techniques. It will also highlight the limitations and challenges of existing methods and the need for camera response model to enhance the low light images.

Project: This chapter will present the proposed method for low light image enhancement using camera response model. It will describe the main components of the method, including decomposition, model parameters, exposure ratio, contrast enhancement and the optimization techniques used to achieve the objectives of the method.

Software description: This chapter will present the MATLAB and basics blocks of MATLAB, MATLAB files, MATLAB tools, mathematical functions of MATLAB and also MATLAB working, from this it is necessary to use this software tool.

Simulation Results: This chapter will present the results of the experiments conducted to evaluate the proposed method. It will analyze the performance of the proposed method and compare it with the state-of-the- art low light enhancement methods in terms of visual quality, color accuracy, structural similarity, and discrete entropy.

Conclusion and future scope: This chapter will summarize the main contributions and findings of the thesis and highlight the significance of the proposed method for improving the visibility and image quality of low light images in real-world scenarios, and also Suggest possible directions for future research, such as exploring other techniques for lowlight image enhancement and camera model, testing the approach on more challenging datasets, or applying it to other image processing tasks.

References: This chapter will provide a list of the references cited in the thesis

CHAPTER 2

BASICS OF DIGITAL IMAGE

Image processing is any form of signal processing for which the input is an image, such as a photograph or video frame; the output of image processing may be either an image or, a set of characteristics or parameters related to the image. Most image processing techniques involve treating the image as a two dimensional signal and applying standard signal-processing techniques to it. Image processing usually refers to digital image processing, but optical and analog image processing also are possible.

2.1 Image

An image is an array, or a matrix, of square pixels (picture elements) arranged in columns and rows

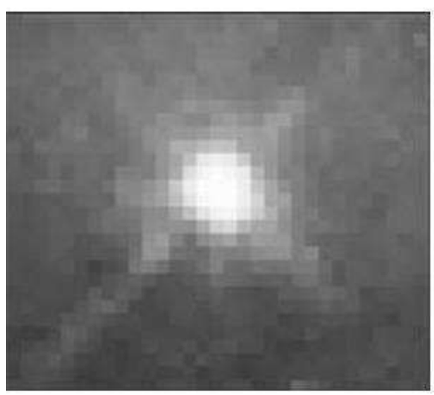

Figure 2.1: An image is an array or a matrix of pixels

2.1.1 Pixel

A picture element is a single point in a graphic image. Every such information part is not actually a dot, nor a square except an conceptual sample. Each element of the above matrix is known as pixel where, dark=0 and bright=1. A pixel with solely 1bit will signify a black and white picture. An image is represented as a matrix in digital image processing. In Digital Signal Processing we utilize only row matrices. Obviously happening images should be sampled and quantized to get a digital image A free image should have 1024*1024 pixels which is known as 1k*1k=1mega pixel.

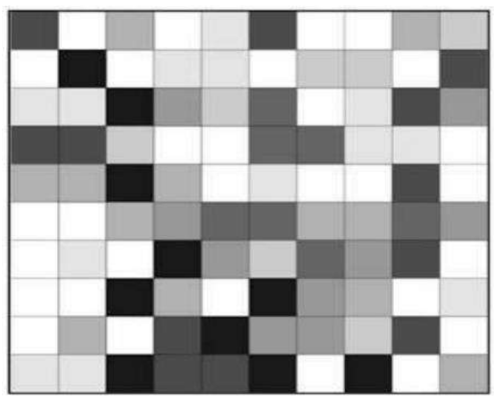

Figure 2.2: Each pixel has a value from 0(black) to 255(bright)

2.2 Types of Image

2.2.1 Gray Scale Image:

Every pixel is a shade of gray, typically from 0(dark) to 255(bright). This extent implies that every pixel can be spoken to by eight bits, or precisely one byte. Other gray scale reaches are utilized, however for the most part they are a force of 2.

2.2.2 Binary Image:

Each pixel is just black or white. Since there are only two possible values for each pixel (0, 1), we only need 1bit per pixel.

2.2.3 Indexed Image:

An index image comprises of an array and a shading guide lattice. Pixels in the exhibit or immediate list into a shading guide. By tradition, this documentation utilizes the variable name x to allude to the exhibit and guide to allude to the shading guide.

2.2.4 RGB Image:

Every pixel has a specific color, that color is depicted by the measure of red, green, and blue in it. On the off chance that each of these segments has an extent 0-255, this gives an aggregate of 2563 different conceivable hues. Such an image is a "stack "of three grids; speaking to the red, green and blue qualities for every pixel. This implies that for each pixel there relate three values.

2.3 Image Digitization:

A picture caught by a sensor is expressed as a continuous function f(x,y) of two directions in the plane. To process a caught picture by PC it must be spoken to in frame work structure. A matrix is the most widely recognized information structure for low level representation of a picture.

Components of the network are whole number numbers relating to splendor or to another property of the comparing pixel of the inspecting lattice. Picture data frame work is available through the directions of a pixel that compare with the line and segment records. Picture digitization implies that the capacity f(x,y) is inspected frame work with M lines and N segments.

2.3.1 Sampling:

A continuous picture function f(x,y) can be inspected utilizing a discrete network of testing focuses in the picture plane. A second plausibility is to extend the picture capacity utilizing some orthogonal capacity as a base-Fourier change. A continuous picture is digitized at sampling focuses. These inspecting focuses are requested in the plane and there geometric connection is known as the GRID. The computerized picture is then an information structure, for the most part a grid. Matrices utilized as part of a practice or typically square and hexagonal. One endlessly little inspecting point in the lattice compares to one picture component in the advanced picture. The set of pixels together covers whole picture. The pixel is a unit, which is not further separable from the picture investigation perspective.

2.3.2 Quantization:

An estimation of the sampled image is determined as a digital value in the image processing. The transition between proceeds with estimations of the capacity and its advanced identical is called quantization. Most digital image processing gadgets use quantization into K equal intervals. In the event that b bits are utilized to express the pixels estimation brightness, then the quantity of the brightness levels is K= 2b. Eight bits for each pixel are usually utilized albeit a few frame works utilize six or four bits. A binary image pixel which is either dark or white can be spoken to by one bit.

2.4 Fundamental Steps in Digital Image Processing:

There are some fundamental steps. But as they are fundamental, all these steps may have sub-steps. The fundamental steps are described in the figure 2.5 as shown below.

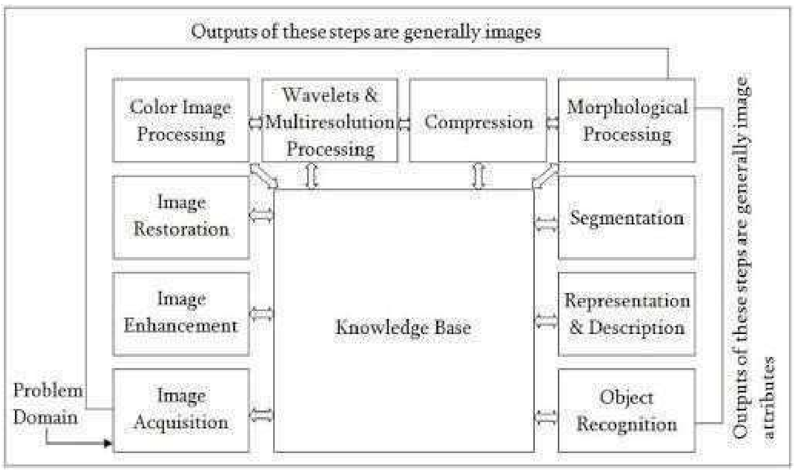

Figure 2.3: Fundamental steps in Digital Image Processing

2.4.1 Image Acquisition:

This is the first step or process of the fundamental steps of digital image processing. Image acquisition could be as simple as being given an image that is already in digital form. Generally, the image acquisition stage involves preprocessing, such as scaling etc.

2.4.2 Image Enhancement:

Image enhancement is among the simplest and most appealing areas of digital image processing basically, the idea behind enhancement techniques is to bring out detail that is obscured, or simply to highlight certain features of interest in an image, such as changing brightness & contrast etc.

2.4.3 Image Restoration:

Image restoration is a range that likewise manages enhancing the presence of the image. On the other hand, not at all like enhancement, which is subjective, image restoration is objective, as in rebuilding methods have a tendency to be founded on numerical or probabilistic models of image degradation.

2.4.4 Color Image Processing:

Color image processing is a range that has been gaining up its significance due to the noteworthy increment in the utilization of advanced images over the internet, this may incorporate color displaying and processing in an advanced space and so on.

Color image processing is an area that has been gaining its importance because of the significant increase in the use of digital images over the internet.

2.4.5 Wavelet and Multi-Resolution Processing:

Wavelets are the establishment for representing to images in different degrees of resolution. Image progressively subdivided into littler regions for information pressure and for pyramidal representation.

2.4.6 Compression:

Compression deals with techniques for reducing the storage required to save an image or the bandwidth to transmit it. Particularly it is used to compress the data.

2.4.7 Morphological Processing:

Morphological processing deals with tools for extracting image components that are useful in the representation and description of shape.

2.4.8 Segmentation:

Segmentation procedures partition an image into its constituent parts or objects or set of pixels, in general, autonomous segmentation is one of the most difficult tasks in digital image processing. A rugged segmentation procedure brings the process a long way toward successful solution of imaging problems that require objects to be identified individually.

2.4.9 Representation and Description:

Representation and description almost always follow the output of a segmentation stage, which usually is a raw pixel data, constituting either the boundary of a region or all the points in the region itself. Choosing are presentation is only part of the solution for transforming raw data into a form suitable for subsequent computer processing. Description deals with extracting attributes that result in some quantitative information of interest or are basic for differentiating one class of objects from another.

2.4.10 Object Recognition:

Recognition is the process that assigns a label, such as, “vehicle” to an object based on its descriptors.

2.4.11 Knowledge Base:

Knowledge may be as basic as specifying districts of an image where the data of premium is known not found, in this way contrasting the hunt that must be led in looking for that data. The learning base additionally can be entirely mind boggling, for example, an interrelated rundown of all real conceivable imperfections in a materials review issue or an image database containing high determination satellite images of a district regarding change detection applications.

2.5 Practical applications of Image processing:

Image processing has a gigantic scope of utilizations; each region of science and innovation can make utilization of image handling strategies. Here is a short run down just to give some sign of the scope of image handling applications.

2.5.1 Document processing:

It is utilized as a part of filtering, and transmission for changing over paper archives to an advanced image structure, compacting the image, and putting away it an attractive tape. It is likewise utilized as a part of archive perusing for consequently identifying and perceiving printed qualities.

2.5.2 Medical Applications:

Investigation and understanding of images acquired from X-beams, MRI or CAT examines, examination of cell images, of chromosome karyo sorts. In restorative applications, one is worried with preparing of midsection X-beams, cineangiograms projection images of transaxial tomography and other medicine of images that happen in radiology, atomic attractive reverberation (NMR) and ultrasonic checking.

Inspection and interpretation of images obtained from X-rays, MRI or CAT scans, analysis of cell images, of chromosome karyo types. In medical applications, one is concerned with processing of chest X-rays, cineangiograms, projection images of transaxial tomography and other medical images that occur in radiology, nuclear magnetic resonance (NMR) and ultrasonic scanning. These images may be used for patient screening and monitoring or for detection of tumours or other disease in patients.

2.5.3 Defence/Intelligence:

It is utilized as a part of observation photographic understanding for programmed elucidation of earth satellite imagery to search of delicate target or military dangers and target securing and direction for perceiving and following focuses progressively brilliant bomb and rocket direction frame works.

2.5.4 Radar Imaging System:

Radar and sonar pictures or utilized for location and acknowledgement of different sort of target or in direction and moving of air ship or rocket frameworks.

2.5.5 Agriculture:

Satellite/airborne perspectives of area, for instance to decide the amount of area is being utilized for purposes, or to examine the suitability of distinctive locales for distinctive yields, review of leafy foods recognizing great and crisp produce from old.

CHAPTER 3
LITERATURE SURVEY

N. Singh and A. K. Bhandari, proposed a new method that is eliminated two complications of dark image improvement. Local over enhancement because of irregular brightness and the insufficiency of adaptableness in the constraint values of enhancement processes. Principal component Analysis-Based low light image enhancement using reflection model method is based on the image formation theory and reflection model. This algorithm boosts dark images without disorganizing their features or establishing artifacts. In this method uses contrast Limited adaptive Histogram equalization technique. This is depends on ρ values or contrast parameter. As ρ decreases, the overall brightness of the processed image is enhanced, but decreasing the ρ value, image becomes more brighter and generated visual artifacts that lead to over enhanced results [1].

A low-light image enhancement method based on the semi decoupled decomposition was proposed by S. Hao, X. Han, and M. Wang to enhance the visual quality of an image and suppressing the noise. During the decomposition process, the illumination layer is individually estimated based on the proposed Gaussian Total Variation filter, while the reflectance layer is jointly estimated based on the retinex constraint. This low-light enhancement model can be easily adjusted to tackle low-light images with different imaging noise levels. There also exist some limitations, for storing and transferring digital images, compression algorithm imposed on an image can produce JPEG artifacts hidden in the originally dark regions. It is limited in generating enhanced images at the semantic-aware and aesthetic-aware level [3].

X. Guo, Y. Li, and H. Ling, proposed a effective and efficient method to enhance low light images via illumination map estimation. Retinex based enhancement methods decompose an image in to reflectance and illumination while low light image enhancement via illumination is based on enhancement of the illumination component of the image. In this method the illumination map is constructed by finding the maximum intensity of each pixel in R,G and B channels. This method show its superiority over several methods in terms of enhancement quality and efficiency. However, despite its brilliant performance with most of images, it tends to cause overexposure to some low light image datasets, which is caused mostly due to the nonuniform illumination map of most low light images [4].

A weighted varaitional model for simultaneous reflectance and illumination estimation proposed a measured adaption model to determine both the reflectance and the illumination component from an image. Based on the analysis of the logarithmic transformation, a weighted variational model is introduced to refine the regularization terms for better prior representation. The method has also been found successful in supressing the background noise of an image. Compared with other variational methods, this method yields comparable or better results on both subjective and objective assessments. Unlike existing variational methods using complex techniques Such as nonlocal techniques and dictionary learning techniques, this proposed model can achieve significant improvement by simply weighting the widely used regularization terms. However, the lack and ignorance toward CRF cause the output images to be distorted and unnatural in their visual appearanc [5] .

Another simple and efficient method was proposed by Y. Ren, Z.Ying, T. H. Li to enhance low light images using camera model. This method evaluate the relationship between two images with different exposers to obtain an accurate camera response model. Then estimate the exposure ratio map. Finally this method use camera response model to adjust each pixel to its desired exposure according to the estimated exposure ratio map. This method is better to obtain enhancement results with less colour and lightness distortion compared to several other methods. This model can reduce the mean RMSE by an order of magnitude compared to that of other existing two-parameter models. It is failure is at sometimes because of the over enhancement can be done on image. If the dark background in the estimated illumination map and therefore is enhanced along with the background [6].

S. Wang, J. Zheng, H.-M. Hu, proposed Naturalness preserved Enhancement Algorithm for Non- Unifrom illumination Images to preserve naturalness and enhances details of the image. In this method a lightness order or measure is proposed to access naturalness presentation objectively. A bright-passfilter is proposed to decompose an image into reflectance and illumination, which is determine the details and the naturalness of the image. The bilog transformation is proposed to process the illumination and make a balance between details and naturalness. The experimental results demonstrate that the proposed algorithm can not only enhance the details but also preserve the naturalness for non-uniform illumination images. However enhancement algorithms does not take into consideration the relation of illumination in different scenes it may introduce slight flickering for video applications [7].

CHAPTER 4
IMAGE ENHANCEMENT BASED ON CAMERA RESPONSE MODEL

The proposed methodology is arranged into three major parts. The first part of the proposed method focuses on decomposing and determining the illumination and reflectance components of the image. The second part focuses on preserving the naturalness of the image. The third part of the proposed method focuses on contrast enhancement.

1. Reflectance and Illumination
2. Camera Response Function
3. Contrast Enhancement

Flow chart:

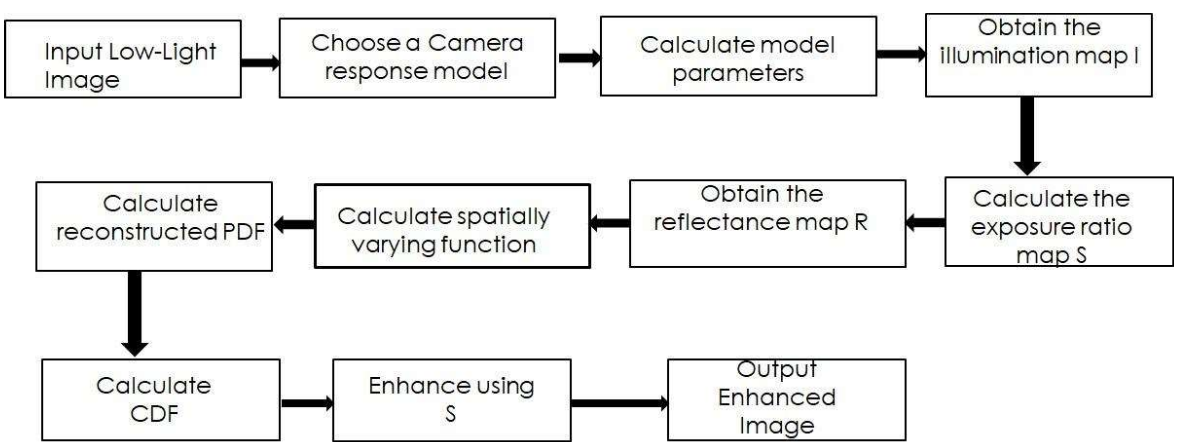

Figure 4.1: Flowchart of the proposed method

4.1 Estimation of Illumination and Reflectance:

An illumination map is a representation of the spatial distribution of illumination in an image. It is a grayscale image that shows the local brightness of the image at each point, and is often used as a pre-processing step for image enhancement, restoration or segmentation tasks. The reflectance map is a representation of the intrinsic reflectance properties of a scene. It describes the amount of light that is reflected by each point in the scene, independent of the illumination conditions. The reflectance map represents the intrinsic reflectance properties of a scene by removing the effects of illumination variations.

Traditional Retinex model assumes that the amount of light reaching observers can be decomposed into two parts as follows

$$\mathbf{T} = \mathbf{R} \circ \mathbf{I} \qquad \mathbf{4.1}$$

where R is the reflectance component of the image with a range of (0, 1], I is the illumination component of the image with a range of (0, ∞) , and "o" denotes the pixelwise multiplication.

$$F(r, i) = ||\mathbf{i} + \mathbf{r} - \mathbf{t}||2^2 + c_1 \; ||\mathbf{e}^r * \mathbf{del\ r}||\mathbf{1} + c_2 \; \left|\left|\mathbf{e}^i * \mathbf{del\ i}\right|\right| 2^2$$

$$\mathbf{s.t.r} <= \mathbf{0\ and\ t} <= \mathbf{I} \qquad \mathbf{4.2}$$

where cl and c2 are the positive parameters and **| | | |** depicts n-norm operator. To eliminate the impact of weights (1/R) and (1 / I) the terms del r and del i are measured by e ^ r and e ^ i respectively. A new objective function based on the calculation that e ^ r = R and e ^ i = I which for the nth iteration, is written as

$$F(\mathbf{r}^{\mathbf{n}}, \mathbf{i}^{\mathbf{n}}) = ||\mathbf{i}^{n} + \boldsymbol{r}^{n} - \boldsymbol{t}^{n}||2^{2} + c_{1}||\mathrm{R}^\wedge\mathrm{n} - 1 * \mathbf{del}\, \boldsymbol{r}^{n}||1 + c_{2}||\boldsymbol{I}^{n} - 1 * \mathbf{del}\, \boldsymbol{I}^{n}||2^{2}$$

$$\mathbf{s.t.}\, \boldsymbol{r}^{n} <= 0 \text{ and } \mathrm{t} <= \mathbf{i}^{n} \qquad \mathbf{4.3}$$

It is observed that traditional gradient descent methods are quite unsuitable for the objective function. To overcome this limitation, an alternating direction method of multiplier (ADMM) is adopted, which introduces a supplementary variable u and an error v. The objective function is thus rewritten as

$$F(\mathbf{r}^{\mathbf{n}}, \mathbf{i}^{\mathbf{n}}, \mathbf{u}^{\mathbf{n}}, \mathbf{v}^{\mathbf{n}}) = ||\mathbf{i}^{\mathbf{n}} + \mathbf{r}^{\mathbf{n}} - \mathbf{t}^{\mathbf{n}}||2^{2} + c_{2}||\mathbf{I}^{\mathbf{n}-1} * \boldsymbol{del}\, \mathbf{i}^{\mathbf{n}} * || + c_{1}\{ ||\mathbf{u}^{\mathbf{n}}||\, 1 + \mathbf{lambda}||\mathbf{R}^{\mathbf{n}-1} * \boldsymbol{del}\, \mathbf{r}^{\mathbf{n}}$$

$$\text{s.t. } \mathbf{r}^{\mathbf{n}} <= 0 \text{ and } \mathrm{t} <= \mathbf{i}^{n} \qquad \mathbf{4.4}$$

Equation (4) proves extremely efficient in determining the reflectance and illumination component of the image, and the measured approach enables the reduction of background noise present in the image.

4.2 Camera Response Model:

The camera response model is a mathematical model used in image processing to correct for the non-itineraries in the response of a camera's image sensor. When light enters a camera, it interacts with the sensor to produce an electrical signal that is then digitized into a digital image. However, the relationship between the amount of light entering the camera and the resulting digital signal is non-linear. This non-linearity can result in distortions in the image, such as color shifts or uneven brightness. The camera response model describes the relationship between the amount of light entering the camera and the resulting digital signal

4.2.1 Camera Response Function

The CRF models the nonlinearity, which is objectively present between the incident light and pixel values in a digitalized image. It is represented as

$$\mathbf{P} = \mathbf{f}(\mathbf{E}) \qquad \mathbf{4.5}$$

where f is the nonlinear CRF function. Equation (5) physically represents a function mapping the pixel values of an image to the image irradiance E, based on the amount of light falling on the image.

4.2.2 Brightness Tranformation Function:

The Brightness Transformation Function (BTF) model is a mathematical model that is used to adjust the brightness and contrast of an image. The BTF model maps the pixel intensities of an input image to a new set of pixel intensities that correspond to a desired brightness and contrast level. The BTF model is typically represented as a mathematical function that takes an input image as its argument and returns a new image with adjusted brightness and contrast. A mapping function BTF between two images P0 and P1 is described as

$$\mathbf{P1} = \mathbf{g}(\mathbf{P0.s}) \qquad \mathbf{4.6}$$

where g is BTF and s is the exposure ratio. From the above two equations the BTF is given as

$$\mathbf{g}(\mathbf{f}(\mathbf{E}), \mathbf{s}) = \mathbf{f}(\mathbf{sE}) \qquad \mathbf{4.7}$$

From equation1 E is divided in to illumination and reflectance then P =f(R ∘ I) and the enhanced image intensity P' is defined as:

$$\mathbf{P'} = \mathbf{f}(\mathbf{R} \circ \mathbf{1}) \qquad \mathbf{4.8}$$

The enhanced image is written as a function of the input image and its exposure ratio. Thus, the BTF is written as

$$\mathbf{P'} = \mathbf{g}(\mathbf{P}, \mathbf{1} \oslash \mathbf{I}) = \mathbf{g}(\mathbf{P}, \mathbf{S}) \qquad \mathbf{4.9}$$

Where **ø** denotes element wise division According to the observations and calculation based on root mean square error (RSME) distribution curves for different CRMS, the sigmoid model of camera response gives the best results. Thus, sigmoid is chosen as CRM for this article. According to the function,

CRF is defined as

$$\mathbf{f}(\mathbf{E}) = (\mathbf{1} + \mathbf{a})(\ \mathbf{E}^{b} \,/\, \mathbf{E}^{b} \ + \ \mathbf{E}^{a}) \qquad \mathbf{4.10}$$

where a and b are parameters . From (9), the BTF of sigmoid is calculated as

$$\mathbf{g}(\mathbf{P}, \mathbf{s}) = \mathbf{s}^{b}\mathbf{P}(\mathbf{1} + \mathbf{a})/(\mathbf{s}^{b} \ - \mathbf{1})\ \mathbf{P} + \mathbf{1} + \mathbf{a} \qquad \mathbf{4.11}$$

According to (9),it is observed that S is inversely proportional to

I. Thus, it is required to first calculate I, so that S is defined as

$$\mathbf{S} = \mathbf{1} \oslash I \qquad \mathbf{4.12}$$

Thus, to address the issue for pixels with low illumination, minimum value of illumination Imin is set as a threshold value, and thus, this modifies (13) as follows:

$$\mathbf{S = 1/max(1, Imin)} \qquad \mathbf{4.13}$$

Following the algorithm above, an enhanced illumination component of the image is achieved, which is free of back-ground noise and its naturalness is well preserved.

4.3 Contrast Enhancement

The most celebrated method for contrast enhancement of an image is HE , while this method is highly effective, its processing works blindly on the entire image and pays no attention to its local details, and this leads to over- or underexposure of the image, especially in low-light images . It is thus necessary to change HE, such that it considers the local or spatial details of the image under consideration.

4.3.1 Spatially Varying Function:

A spatially varying function can be used to represent how the brightness or color of each pixel in an image varies across the image. One way to achieve this is by using illumination, which refers to the amount and direction of light that falls on each pixel in the image. To create a spatially varying function using illumination, one approach is to model the illumination as a function of position in the image.

$$\boldsymbol{\varphi(q) = \pi \prod_{i==1}^{L} U(\varphi i(q))} \qquad \mathbf{4.14}$$

where U() is the upsampling operator with factor 2^i-1and φ (q) spatially varying function.

4.3.2 Probability Density Function (PDF):

Probability density function (PDF) refers to a function that describes the probability distribution of pixel intensity values in an image. Reconstructing a PDF involves estimating the underlying probability distribution based on the available image data. For the input image, A={a(q)} , where a(q) ∈ [0, K) is the intensity of each pixel q and K is the total number of intensities. If nk is the number of occurrences of each pixel of intensity k ∈ [0, K) , then the probability density function (pdf) of the image is

$$\mathbf{pa}\,(\mathbf{k}) = \mathbf{nk/n} \qquad \mathbf{4.15}$$

where n is the total number of pixels.

4.3.3 Cumulative distributive Function (CDF):

The cumulative distribution function (CDF) is a function that describes the cumulative probability of pixel intensity values in an image. The CDF is defined as the integral of the probability density function (PDF) from negative infinity to a given pixel intensity value. To calculate the CDF of an image, we first need to compute the PDF of the image. Once we have the PDF, we can compute the CDF by accumulating the PDF values over the range of pixel intensity values.

Cumulative distributive function (cdf) is denoted as $\mathbf{P_a(k)}$ and it is further needed to find a mapping function J (a) that can produce the HE-enhanced image B = {b(q)} . In the case of HE, the mapping function produces an image that has a linearized cdf. Let Pb(k) denote the cdf of the output image, then the mapping function is defined as

$$\boldsymbol{J}(\boldsymbol{K}) = \mathbf{argmin}\left|\boldsymbol{P_b}(\mathbf{J}(\mathbf{k})) - \boldsymbol{P_a}(\mathbf{k})\right|$$

$$= \boldsymbol{P_b}^{-1} * (\boldsymbol{P_a}(\mathbf{k}))$$

$$= (\mathbf{K} - \mathbf{1}) * \boldsymbol{P_a}(\mathbf{k}) \qquad \mathbf{4.16}$$

This mapping function when applied to A gives histogram equalized output B. However, the increment output intensity versus a unit step up in input intensity k - 1 is easily seen to be

$$\mathbf{del\,J(k)} = \mathbf{J(k)} - \mathbf{J(k-1)} = (\mathbf{K} - \mathbf{1}) * \boldsymbol{P_a}(\mathbf{k}) \qquad \mathbf{4.17}$$

Equation (17) shows that the increment in intensity is proportional to the probability of the corresponding intensity of the input image. This property causes the results of HE to have background noise or be over- or underexposed. To overcome this, a method is devised that reconstructs HE by incorporating spatial information into the density estimation of the image. Equation (16) is thus redefined as follows:

$$\boldsymbol{P_a}'(\mathbf{K}) = \sum \mathbf{q}\ \boldsymbol{\varphi}(\mathbf{q})\boldsymbol{\delta}(\boldsymbol{\alpha}(\mathbf{q}), \boldsymbol{\kappa}) / \sum \mathbf{q}\ \boldsymbol{\varphi}(\mathbf{q}) \qquad \mathbf{4.18}$$

where **δ** represents the Kronecker delta and is a spatially varying function defined using R calculated using (4). This is a novel equation for pdf function of an image. This newly defined equation brings forth local details of the image since it is based on spatial details of the images unlike the historical equation which is calculated uniformly for the entire image.

CHAPTER-5

SOFTWARE DESCRIPTION

The hardware and software specifications are important in designing the new system. The hardware system is selected considering the factors such as CPU processing speed, memory access speed, peripheral channel speed, seek time, communication speed etc. To implement the proposed system, specified software configuration is also needed. The requirement analysis will specify both the hardware and software configuration of the proposed system.

5.1 HARDWARE SPECIFICATION

Processor	:	Dual core
processor Hard Disk	:	160GB
Disk Space	:	3–4 GB
RAM	:	2 GB
Keyboard	:	104 Keys
Mouse	:	HID Complaint Mouse

5.2 SOFTWARE SPECIFICATION

Operating system	:	Windows XP
Coding Language	:	MATLAB R2010a

5.3 LANGUAGE DESCRIPTION

MATLAB is a program that was originally designed to simplify the implementation of numerical linear algebra routines. It has since grown into something much bigger, and it is used to implement numerical algorithms for a wide range of applications.

5.3.1 The Language of Technical Computing

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation. Using MATLAB, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and FORTRAN. You can use MATLAB in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modelling and analysis, and computational biology.

5.3.2 Key Features

- High-level language for technical computing
- Development environment for managing code, files, and data
- Interactive tools for iterative exploration, design, and problem solving
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration
- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java, COM, and Microsoft Excel.

5.4 DEVELOPMENT TOOLS

MATLAB includes development tools that help you implement your algorithm efficiently. These include the following:

- **MATLAB Editor** - Provides standard editing and debugging features, such as setting breakpoints and single stepping.
- **Code Analyzer** - Checks your code for problems and recommends modifications to maximize performance and maintainability.
- **MATLAB Profiler** - Records the time spent executing each line of code.
- **Directory Reports** - Scan all the files in a directory and report on code efficiency, file differences, file dependencies, and code coverage.

5.4.1 Designing Graphical User Interfaces

You can use the interactive tool GUIDE (Graphical User Interface Development Environment) to layout, design, and edit user interfaces. GUIDE lets you include list boxes, pull-down menus, push buttons, radio buttons, and sliders, as well as MATLAB plots and ActiveX controls. Alternatively, you can create GUIs programmatically using MATLAB functions.

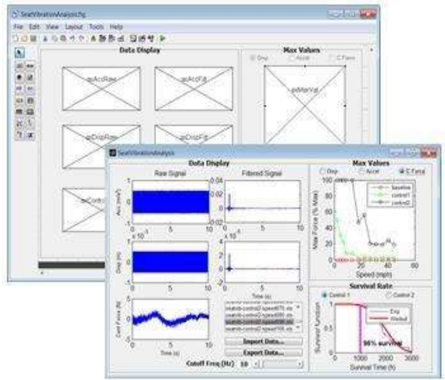

Figure: 5.1 Graphical User Interface

5.4.2 Analyzing and Accessing Data

MATLAB supports the entire data analysis process, from acquiring data from external devices and databases, through preprocessing, visualization, and numerical analysis, to producing presentation-quality output.

5.4.3 Data Analysis

MATLAB provides interactive tools and command-line functions for data analysis operations, including:

- Interpolating and decimating
- Extracting sections of data, scaling, and averaging
- Thresholding and smoothing
- Correlation, Fourier analysis, and filtering
- 1-D peak, valley, and zero finding
- Basic statistics and curve fitting
- Matrix analysis

5.4.4 Data Access

MATLAB is an efficient platform for accessing data from files, other applications, databases, and external devices. You can read data from popular file formats, such as Microsoft Excel; ASCII text or binary files; image, sound, and video files; and scientific files, such as HDF and HDF5. Low-level binary file I/O functions let you work with data files in any format. Additional functions let you read data from Web pages and XML.

5.4.5 Visualizing Data

All the graphics features that are required to visualize engineering and scientific data are available in MATLAB. These include 2-D and 3-D plotting functions, 3-D volume visualization functions, tools for interactively creating plots, and the ability to export results to all popular graphics formats. You can customize plots by adding multiple axes; changing line colours and markers; adding annotation, LaTeX equations, and legends; and drawing shapes.

5.5 2-D Plotting

You can visualize vectors of data with 2-D plotting functions that create:

- Line, area, bar, and pie charts
- Direction and velocity plots
- Histograms
- Polygons and surfaces
- Scatter/bubble plots
- Animations

5.6 The MATLAB System

The MATLAB language supports the vector and matrix operations that are fundamental to engineering and scientific problems. It enables fast development and execution. With the MATLAB language, you can program and develop algorithms faster than with traditional languages because you do not need to perform low-level administrative tasks, such as declaring variables, specifying data types, and allocating memory. In many cases, MATLAB eliminates the need for „for‟ loops. As a result, one line of MATLAB code can often replace several lines of C or C++ code.

At the same time, MATLAB provides all the features of a traditional programming language, including arithmetic operators, flow control, data structures, data types, object-oriented programming (OOP), and debugging features. MATLAB lets you execute commands or groups of commands one at a time, without compiling and linking, enabling you to quickly iterate to the optimal solution.

5.7 Dataset and Features

There is a total of 86,147 images of diseased and healthy plants. These images span 25 different species of plants. Each set of images, such as the training, validation, and testing, span 25 different species of plants. The training set includes 55,135 images of disease and healthy plant leaves. that also span 25 different species of plants. The validation set includes 13,783 images of disease and healthy plant leaves. The testing set includes 17, 229 images of disease and healthy plant leaves. All images were segmented to remove the background. In addition, all images were resized to have a width of 64 pixels and a height of 64 pixels. Then this was repeated for images that were segmented.

CHAPTER-6
RESULT ANALYSIS

Low light image enhancement based on camera response model proposes a novel method for enhancing night time images using a camera response model. The method involves acquiring two images with different illumination conditions and estimating the camera response function using these images. The camera response function is then used to enhance the low light image by adjusting the reflectance values. The camera response function estimation also contributed significantly to the performance of the proposed method. The proposed method was tested on a dataset of night time images captured under low light conditions.

The objective evaluation involved using metrics such as structural similarity index (SSIM), Visual saliency induced index(VSI) and Discrete Entropy(DE) to compare the enhanced images with the original images. The results of the objective evaluation showed that the proposed method achieved a significant improvement in terms of SSIM,VSI and DE values. The results were compared with the original images and with the state-of-the- art methods for nighttime image enhancement.

The result analysis of camera response based low light image enhancement should show an improvement in image quality, with reduced noise, improved contrast, and accurate color representation. The method was able to enhance the visual quality of the low light images while preserving their details and reducing noise

Figure 6.1: Original Image

Figure 6.2: Illuminant Image

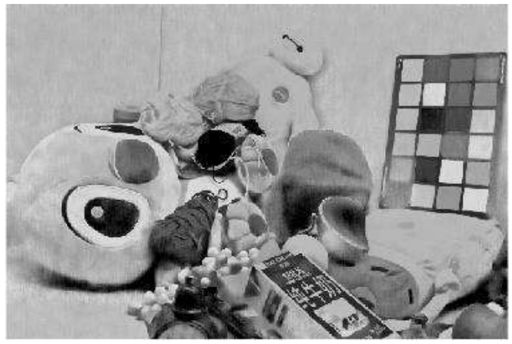

Figure 6.3: Reflectance Image

Figure 6.4: Enhanced Image

Table 6.1 : Comparison Table

METHOD	NIQE	SSIM	VSI	DE	TIME
LIME	3.8574	1.4813	0.3964	0.9970	2.4344
PROPOSED	3.8446	0.9856	0.8417	5.9928	1.4075

6.1 DEFINTION:

6.1.1 NIQE (Natural Image Quality Evaluator):

NIQE is based on an analysis of the statistics of natural images and is designed to evaluate the quality of images that are degraded by various types of distortion such as blur, noise, and compression artifacts. NIQE values typically range from 0 to 20, where lower values indicate better image quality.

6.1.2 SSIM (Structural Similarity Index):

SSIM stands for Structural Similarity Index and is a widely used metric for measuring the similarity between two images. SSIM is calculated by comparing the luminance, contrast, and structural similarity between the two images being compared. The result is a value between 0 and 1, with 1 indicating a perfect match and 0 indicating no similarity.

6.1.3 VSI (Visual Saliency Index):

VSI stands for Visual Saliency Index. It is a metric used to quantify the visual saliency of an image, which refers to the degree to which certain regions of the image stand out and draw the viewer's attention. The VSI is based on the principle of information theory, which states that salient regions of an image contain more information than non-salient regions. The closer VSI is to 1, the better the image quality.

6.1.4 DE (Discrete Entropy) :

In image processing, discrete entropy is a measure of the amount of information present in an image. It is based on the concept of entropy from information theory, which measures the uncertainty or randomness of a system. In practice, the entropy values for better images are typically in the range of 6 to 7 bits per pixel. This range provides a good balance between image complexity and noise reduction.

6.2 DESCRIPTION:

Image quality can degrade due to distortions during image acquisition and processing. Examples of distortion include noise, blurring, ringing, and compression artifacts.

Efforts have been made to create objective measures of quality. For many applications, a valuable quality metric correlates well with the subjective perception of quality by a human observer. Quality metrics can also track unperceived errors as they propagate through an image processing pipeline, and can be used to compare image processing algorithms.

6.2.1 SSIM :

The concept of SSIM, or Structural Similarity Index, is another widely used metric in image processing that is used to measure the similarity between two images. The formula for calculating SSIM is:

$$\mathbf{SSIM}(\mathbf{x},\mathbf{y}) = [\mathbf{l}(\mathbf{x},\mathbf{y}) * \mathbf{c}(\mathbf{x},\mathbf{y}) * \mathbf{s}(\mathbf{x},\mathbf{y})] \qquad \mathbf{6.1}$$

where x and y are the two images being compared, l(x,y) is the luminance comparison, c(x,y) is the contrast comparison, and s(x,y) is the structural comparison.

The luminance comparison measures the similarity in brightness between the two images, while the contrast comparison measures the similarity in contrast between the two images. The structural comparison measures the similarity in the patterns of textures and edges between the two images.

SSIM values range from -1 to 1, with 1 indicating perfect similarity between the two images. Generally, a value above 0.9

is considered good, while values below 0.6 are considered poor. However, it is important to note that the specific threshold for what constitutes a "good" or "poor" SSIM value can vary depending on the application and the requirements of the user.

6.2.2 NIQE:

NIQE (Natural Image Quality Evaluator) is a no-reference image quality assessment metric that measures the quality of a digital image without using a reference image for comparison. NIQE is based on an analysis of the statistics of natural images and is designed to evaluate the quality of images that are degraded by various types of distortion such as blur, noise, and compression artifacts. NIQE is calculated using a set of features that capture the statistical properties of natural images. These features include: Discrete Cosine Transform (DCT) statistics Color moments Gradient statistics Laplacian statistics Gabor filter responses. The NIQE metric is computed as the weighted sum of these features, where the weights are determined by a regression analysis that predicts human perception of image quality. NIQE values typically range from 0 to 20, where lower values indicate better image quality. The specific range of NIQE values that correspond to high or low image quality depends on the application and the specific dataset used for training the NIQE model.

6.2.3 VSI:

VSI stands for Visual Saliency Index. It is a metric used to quantify the visual saliency of an image, which refers to the degree to which certain regions of the image stand out and draw the viewer's attention. The VSI is based on the principle of information theory, which states that salient regions of an image contain more information than non-salient regions.

The equation for VSI can be written as follows:

$$\mathbf{VSI} = (\mathbf{1/N}) * \boldsymbol{\Sigma}[\mathbf{i = 1\ to\ N}\ (\mathbf{S[i]/M[i]})] \qquad \mathbf{6.2}$$

where N is the total number of pixels in the image, S[i] is the saliency value of pixel i, and M[i] is the mean value of the saliency map in a small neighborhood around pixel i. The saliency value of a pixel can be computed using various methods, such as frequency- domain analysis or local contrast measures. The resulting VSI value is a normalized score between 0 and 1, where higher values indicate that the image contains more salient regions. The VSI can be used in various applications, such as image segmentation, object recognition, and visual attention modeling.

6.2.4 DE:

In image processing, discrete entropy is a measure of the amount of information present in an image. It is based on the concept of entropy from information theory, which measures the uncertainty or randomness of a system. In the context of images, the entropy is calculated from the histogram of pixel intensities. The histogram is a plot of the number of pixels in the image that have a particular intensity value. The entropy of the image can then be calculated as:

$$\mathbf{H} = -\boldsymbol{\Sigma}\,(\mathbf{p(i)} * \mathbf{log2}(\mathbf{p(i)})) \qquad \mathbf{6.3}$$

where p(i) is the probability of a pixel having intensity i and log2 is the base-2 logarithm. The entropy value ranges from 0 (for a completely uniform image) to the maximum entropy value, which is log2(N), where N is the number of possible intensity values in the image. The entropy of an image can be used as a measure of its complexity or information content. Images with high entropy values tend to have more complex and varied textures, while images withlow entropy values tend to be more uniform and simple.

Discrete entropy is used in various applications of image processing, such as image segmentation, object recognition, and compression. In compression, the entropy of an image can be used to determine the optimal coding scheme for reducing the amount of data needed to represent the image. In practice, the entropy values for better images are typically in the range of 6 to 7 bits per pixel. This range provides a good balance between image complexity and noise reduction. However, it's important to note that the optimal range of entropy values may vary depending on the specific application and the desired level of image quality.

CHAPTER 7

CONLUSION & FUTURE SCOPE

7.1 CONCLUSION:

This methodology introduces an innovative technique to enhance low light images in order to bring forth the details hidden in them, while simultaneously preserving their naturalness in order to make these images appear visually more attractive and scientifically more useful. The statistical and visual comparison of a dataset of 426 images shows the supremacy of the proposed CRNIE over other celebrated methods in terms of parametric values and visual outputs. The time complexity evaluation of the proposed method signifies the efficiency of the proposed method in real-life applications. The demonstration of the implementation of the proposed method highlights the practicality of the proposed method, while peer evaluation has been shown to ascertain the effectiveness of the method. Further improvement of the proposed work includes the enhancement of images with white Gaussian noise.

7.2 Future Scope:

Low-light image enhancement based on camera response model is an active research area with many potential future directions. One possible future direction is the development of algorithms specifically designed for multi-camera systems, which are becoming increasingly popular in applications such as surveillance and robotics. Real-time processing is another area where future research could be focused, with the goal of developing faster algorithms that can run in real-time, enabling real-time applications such as video streaming or autonomous vehicles. Deep learning techniques have also shown promise in low-light image enhancement, and future research could focus on developing deep learning-based algorithms that can learn from large datasets of low-light images to produce better results. Another possible direction is the development of algorithms that are robust to noise, which is a common issue in low-light images. Finally, adaptive enhancement algorithms could be developed to automatically adjust the level of enhancement based on the image content, enabling better results for a wide range of images. Overall, low-light image enhancement based on camera response model is a promising area with many potential future directions, and ongoing research in this field could lead to significant improvements in the quality of low-light images and enable new applications in a range of industries.

REFERENCES

[1] N. Singh and A.K. Bhandari, “Principal component analysis- based lowlight image enhancement using reflection model,” IEEE Trans. Instrum. Meas., vol. 70, pp. 1–10, 2021.

[2] K. Srinivas and A. K. Bhandari, “Low light image enhancement with adaptive sigmoid transfer function,” IET Image Process., vol. 14, no. 4,pp. 668–678, Mar. 2020.

[3] S. Hao, X. Han, Y. Guo, X. Xu, and M. Wang, “Low-light image enhancement with semi-decoupled decomposition,” IEEE Trans .Multimedia, vol. 22, no. 12, pp. 3025–3038, Dec. 2020

[4] X. Guo, Y. Li, and H. Ling, “LIME: Low-light image enhancement via illumination map estimation,” IEEE Trans. Image Process., vol. 26,no. 2, pp. 982–993, Feb. 2017.

[5] X. Fu, D. Zeng, Y. Huang, X.-P. Zhang, and X. Ding, “A weighted variational model for simultaneous reflectance and illumination estimation,” in Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR), Jun. 2016,pp. 2782–2790.

[6] Y. Ren, Z. Ying, T. H. Li, and G. Li, “LECARM: Low-light image

enhancement using the camera response model,” IEEE Trans. Circuits Syst. Video Technol., vol. 29, no. 4, pp. 968–981, Apr. 2018

[7] S. Wang, J. Zheng, H.-M. Hu, and B. Li, “Naturalness preserved enhancement algorithm for non- uniform illumination images ” IEEE Trans. Image Process., vol. 22, no. 9, pp. 3538–3548, Sep. 2013.