UNIVERSITI PUTRA MALAYSIA

FUSION OF CLAHE-BASED IMAGE ENHANCEMENT WITH FUZZY SET THEORY ON FIELD IMAGE

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By

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

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Field image can be defined as image captured from handphone or any mobile device in open or outdoor environment. Field image is also known as low quality, low resolution, noise and affected background. In contrast, image captured in lab or studio is a high-quality image taken in a proper setup using high specification device. In agriculture, field leaf image is commonly used to identify plant disease. Accurate detection of plant disease is needed to strengthen the field of agriculture and economy of the country. The disadvantages of field leaf image, are low resolution, low contrast, blur and unsharp due to inconsistent setting or environment exposures. Image enhancement method helps to improve image quality, reduce impulsive noise, and sharpen the edges of field leaf image. In this study, measurement of contrast level is used to compare the quality between field leaf image and image taken in the studio (lab image). High quality image has high contrast value and it shows that lab image has high contrast value. Therefore, this research is focus on field leaf image enhancement to improve the quality of the image and make it as same quality as lab image. This research presents a framework of fusion techniques namely, Contrast-Limited Adaptive Histogram Equalization (CLAHE), Unsharp Masking (USM) and Fuzzy theory. CLAHE-based and USM image enhancement techniques are widely used to enhance and sharpen the edge of field leaf image. However, the drawback of these techniques is the field leaf image is still in low contrast and not as same quality as the lab image. To further improve the quality of field leaf image, combine the existing framework with Fuzzy Set Theory. Furthermore, there are significant difference when applying the framework in global and local images. Therefore, comparison the performance of the framework is done between global and local images. The result of the proposed image enhancement framework is compared with the lab image as a benchmark. From the results shows that the proposed image enhancement framework produces better quality of field leaf image and required minimum processing time. The evaluation measurement methods used in this research are Contrast Value, Contrast Difference (DC), Contrast Improvement Index (CII) and Peak-Signal-Noise-Ratio (PSNR). The proposed fusion framework proved that field leaf image produces better quality image where the CII value increased from 86% to 94%. It also shows that local-based image enhancement with 4x4 patches produce better quality from global-based image enhancement.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah master.

PENINGKATAN IMEJ MELALUI GABUNGAN KAEDAH CLAHE DAN SET FUZZY PADA IMEJ LAPANGAN

Oleh

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Imej Lapangan dapat didefinisikan sebagai gambar yang ditangkap menggunakan telefon bimbit atau peranti mudah alih lain di persekitaran terbuka atau di kawasan luar. Imej lapangan juga dikenali sebagai imej yang rendah kualiti, beresolusi rendah, mempunyai kesan hingar serta latar belakang yang terjejas. Sebaliknya imej yang ditangkap di dalam makmal atau studio adalah gambar berkualiti tinggi yang diambil dengan persediaan yang betul dan menggunakan peranti yang berspesifikasi tinggi. Di dalam bidang pertanian, imej lapangan kebiasaannya digunakan untuk mengenalpasti penyakit tumbuhan. Pengesanan penyakit tumbuhan yang tepat diperlukan bagi memperkasakan bidang pertanian dan ekonomi negara. Kelemahan imej daun lapangan, adalah mempunyai resolusi yang rendah, nilai kontras rendah, imej kabur dan tidak tajam disebabkan oleh tetapan atau pendedahan persekitaran yang tidak konsisten. Kaedah peningkatan imej membantu meningkatkan kualiti imej, mengurangkan hingar impulsif dan menajamkan tepi imej daun medan. Dalam kajian ini, pengukuran tahap kontras digunakan untuk membandingkan kualiti antara imej daun lapangan dan imej yang diambil di studio (imej makmal). Imej berkualiti tinggi mempunyai nilai kontras yang tinggi dan ia menunjukkan imej makmal mempunyai nilai kontras yang tinggi. Oleh itu, kajian ini tertumpu kepada penambahbaikan imej daun lapangan untuk meningkatkan kualiti imej dan menjadikannya sama kualiti dengan imej makmal. Penyelidikan ini membentangkan rangka kerja teknik gabungan iaitu, Contrast-Limited Adaptive Histogram Equalization (CLAHE), Unsharp Masking (USM) dan teori Fuzzy. Teknik penambahbaikan imej berasaskan CLAHE dan USM digunakan secara meluas untuk meningkatkan dan menajamkan tepi imej daun lapangan. Walau bagaimanapun, kelemahan teknik ini adalah imej daun lapangan masih dalam kontras yang rendah dan tidak sama kualiti dengan imej makmal. Untuk meningkatkan lagi kualiti imej daun lapangan, gabungan rangka kerja sedia ada

dengan teori set Fuzzy. Tambahan pula, terdapat perbezaan yang ketara apabila menggunakan rangka kerja dalam imej global dan tempatan. Oleh itu, perbandingan prestasi rangka kerja dilakukan antara imej global dan tempatan. Hasil daripada rangka kerja peningkatan imej yang dicadangkan dibandingkan dengan imej makmal sebagai penanda aras. Daripada keputusan menunjukkan bahawa rangka kerja peningkatan imej yang dicadangkan menghasilkan kualiti imej daun lapangan yang lebih baik dan masa pemprosesan minimum yang diperlukan. Kaedah pengukuran penilaian yang digunakan dalam penyelidikan ini ialah Nilai Kontras, Perbezaan Kontras (DC), Indeks Penambahbaikan Kontras (CII) dan Nisbah Bunyi-Isyarat Puncak (PSNR). Rangka kerja gabungan yang dicadangkan membuktikan imej daun lapangan menghasilkan imej yang lebih berkualiti di mana nilai CII meningkat daripada 86% kepada 94%. Ia juga menunjukkan bahawa peningkatan imej berasaskan tempatan dengan pecahan 4x4 imej menghasilkan kualiti yang lebih baik daripada peningkatan imej berasaskan global.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

C	Universiti Putra Malaysia
CD	Contrast Difference
CII	Contrast Improvement Index
CLAHE	Contrast-Limited Adaptive Histogram Equalization
USM	Unsharp Masking
PSNR	Peak-Signal-Noise-Ratio

CHAPTER 1

INTRODUCTION

1.1 Research Inspiration

Crops are being affected by uneven climatic conditions leading to decreased agricultural yield. This affects the global agricultural economy. Moreover, the condition becomes even worst when any disease infects the crops. Also, increasing population burdens farmers to increase yield. This is where modern agricultural techniques and systems are needed to detect and prevent the crops from being affected by different diseases (Santhosh Kumar & Raghavendra, 2019).

It is difficult to detect the crops when the field image captured is in low image quality. The quality of field leaf image is usually appearing blur, noise and low quality compared to lab image. In this research, a sequential field image enhancement is proposed to increase the quality of field image equivalent to lab image quality. Our algorithm is based on the fusion of several image enhancement techniques, which does not require specialised hardware or knowledge about the field leaf environment conditions. Our algorithm combines contrast enhancement techniques and adaptive histogram equalization techniques. Comprehensive validation experiments performed on the field leaves images to reveal that the proposed framework performs better in enhancing the image quality and can increase the accuracy level.

Image is better than any kind of information for human perception. Vision helps us to perceive and understand nature. In other words, images are invaluable as they provide an efficient means of communication, recording, and storing information. Digital image processing techniques contain different ways for the manipulation of digital images and their enhancement, modification, and analysis (A. Singh and Dogra 2014).

Image enhancement is a technique that helps to improve the quality of an image. The quality of the field leaf image is low compared to the images that were shot in the lab. The lab image provides a sufficient setup in terms of lighting, environment, and proper device to capture the image. The Fuzzy set theory has recently become more and more popular in the leaf of image processing and pattern recognition. The reason is that many image properties, such as brightness, darkness, boundary, and region, are fuzzy in nature. It is not easy to determine the membership function for brightness or darkness for each gray level image. However, brightness is one of the most important pieces of information for gray level images (Patel et al. 2015). Thus, our motivation is to find a method that can objectively and effectively determine the brightness membership function for gray level in an image. The "brightness of gray level" is a fuzzy event. According to the Maximum Entropy Principle, a fuzzy event contains most information when its associated entropy is maximum (Hasikin and Isa 2012b). Our purpose, therefore, is to find a brightness membership function for images such that the corresponding fuzzy event bright has maximum entropy.

1.2 Research Background

Field image is a collection of images captured in the field with many exposures. The outdoor environment has an uncontrol environment due to lack of light or too many light changes. This field image needs an enhancement process to make the result more suitable for a particular application. Usually, the field image has features such as not being sharp, blurry, out-of-focus, lack of highlighting edges, need to improve contrast and brightness, and noise. The collection of field leaf images was taken from the Leafsnap.com dataset and research area at MARDI. Field images from the Leafsnap.com dataset are typical images taken by mobile devices, mostly iPhones (Kumar et al., n.d. 2012), as shown in Figure 1.1. Leafsnap dataset contains 23,147 lab images and 7,719 field images for 185 tree species from the Northeastern United States.

Figure 1.1: Field Image from Leafsnap.com dataset

While a lab image is a collection of images captured in the lab with a proper camera or equipment setting, a lab image is captured in a proper lab environment setup with specific equipment. The illustration of the lab image capturing setup process is shown in section 2.1. A special camera is mounted at the same height that has been measured, and several light units are placed to ensure that the lighting rate received in the lab image is even. The object of the research will be placed in the specific same place known as a backdrop for photography purposes. This method allows the pictures taken in this lab to have consistent quality for all the pictures in the lab image collection. In this research, lab images collection is used from the Leafsnap.com dataset as well which these pressed leaves were captured with the same setting of light and sharpness. The collection of lab images obtained from Leafsnap has the same setting. The leaf object is pressed, then the process of capturing an image using a suitable setting as desired with special equipment to ensure the image quality is as prescribed. Therefore, these lab images consistently have the same quality with the contrast and brightness required according to the set settings. These lab images were snap backlit and front-lit from different samples of species. The images are consistent with low contrast and contain high in light.

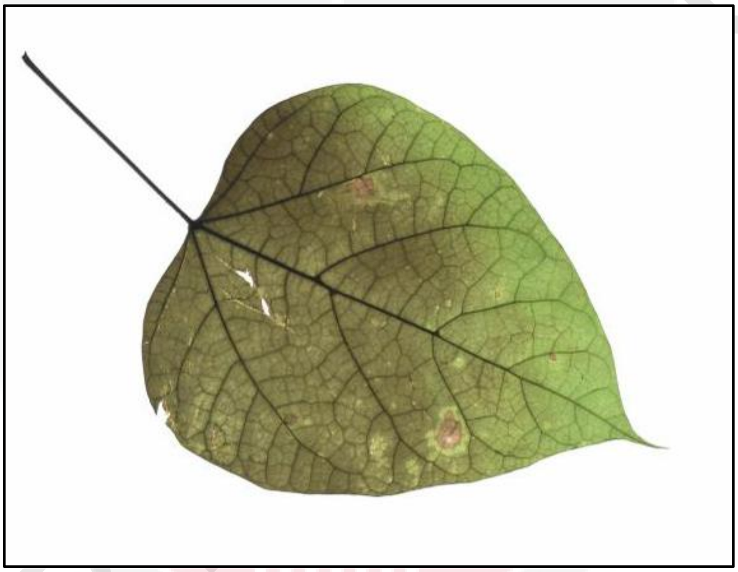

Figure 1.2: Lab image from Leafsnap.com dataset

In this research project, we also developed our dataset with data collection taken from the research area in MARDI. Three different devices were used for field images data collection: iPhone 5, Lenovo A5600 and Mi A2 dual camera. These images need to have an algorithm to correct the color and brightness of the image captured by the different sensors (Qureshi, Beghdadi, and Deriche 2017). Dataset from the research area at MARDI is shown in Figure 1.3 until Figure 1.5. The surroundings and factors of natural light are uncontrollable attributes. Therefore, for our own created dataset in this research, we focus on taking one piece of leaf in white background with an outdoor environment. The image shown in Figure 1.3 was taken using iPhone 5, Figure 1.4 was taken using Lenovo A5600, and Figure 1.5 was taken using Mi A2 dual camera at research area at MARDI.

The sample of pictures in figures 1.3 to 1.5 looks good because they were taken using a high-resolution phone camera and did not have many lousy lighting effects or vibrations. However, the contrast quality in this picture is low compared to the lab picture quality. This is the factor that causes this image to look still quite dark, and the texture on the image is not as clear as the lab image. So, this quality factor still has room for improvement to get better contrast quality.

Figure 1.3: Field Image from research area at MARDI dataset captured using iPhone 5

Figure 1.4: Field Image from Research Area at MARDI dataset captured using Lenovo A5600

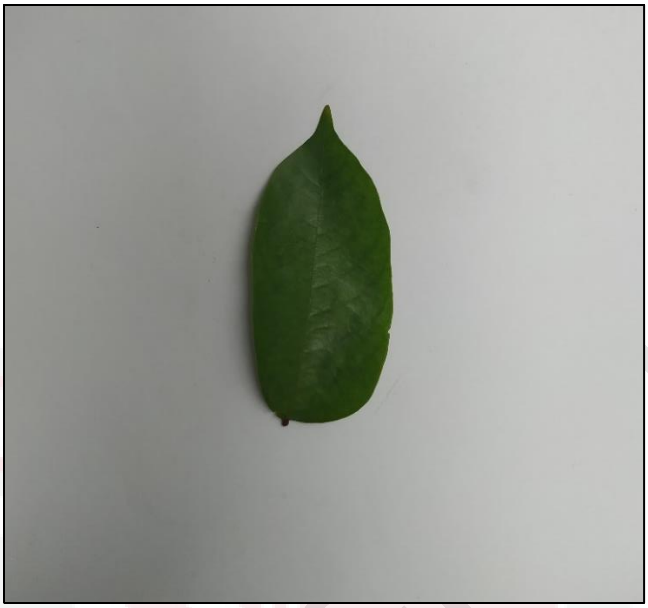

Figure 1.5: Field Image from Research Area at MARDI dataset captured using MI A2 Dual Camera.

Image enhancement can improve the quality factor of low resolution and bad contrast value in the field image. These field images were not suitable to be used in image preprocessing or features extraction due to their bad quality (Bedi and Khandelwal 2013) (G. Kaur & Kumar, 2020). Furthermore, they could not be used in the recognition system as they provide less information. The best image quality is defined as an image with high resolution, which is the photos can be expressed as pixels (or dots) across by pixel down, such as 300 dots per inch (dpi).

However, when doing image processing for an outdoor environment, the exposure, contrast, highlights, shadows, and color temperature are the first things to adjust. An image must have proper brightness and contrast for easy viewing. Contrast is a difference in brightness between object and region, while brightness refers to the overall darkness or lightness of the image. Even for monitor (computer, gadget, or television) display has a specific setting to ensure the sharpness or distortion of the view on the screen is suitable for human vision. The brightness of an image depends on visual perception. Brightness can be defined as the amount of energy output by a light source relative to the source that compares which can be perceived (Chiang and Chen 2012). Contrast is the difference in luminance or color in an image or display that can be distinguished (Denman et al. 2018). In the visual perception of the real world, contrast is determined by the difference in color and brightness of objects and other objects in the same field of view.

1.3 Problem Definition

Field image is known as image capture using a handphone or any mobile device in an open or outdoor environment. Field image is also known as low quality, low resolution, noise and affected background. This is due to exposure to environmental factors such as insufficient or diminished light, which leads to too light or too dark of the image. Furthermore, the other factors that can affect image quality are shadow and vibration when snapping the picture. This field image is a low-resolution image which blurred, noisy and has low contrast. This can affect other image processing results, such as recognition, as the obtained results can be less than expected. Thus, there is a need for an image enhancement to transform a low-resolution image into a good quality image. Image enhancement removes blur and noise, increases smoothness, and sharpens the image, increasing the contrast of the field image. Many algorithms have been devised to improve image quality. The problem is how to enhance the low-quality image without reducing the information. CLAHE-based image enhancement method is widely used to increase the smoothness and edge of the image. The CLAHE technique can improve the contrast quality in the image. This technique has been popularly used in many past studies. However, this technique alone cannot increase the brightness and sharpness of an image. Therefore, combining the CLAHE technique with other methods is expected to provide better quality, especially if the field image is compared to the lab image quality. As informed, field image is not only low contrast quality but also has the problem of blur and light, which is quite dark or less brightness when compared to lab image quality.

Plant image processing has received considerable attention over the last few decades due to its challenging nature and its importance for the environment (Cerutti et al., 2013; Hasikin & Isa, 2012a; Zheng et al., 2017b). Basic light attributes contain these qualities are direction, intensity, form, color, and movement. These attributes can be manipulated to control the quality of the attributes in the lab images setup. But for the outdoor environment, the surrounding factors will influence uncontrollably. (Kim et al., 2020; Vit & Shani, 2018). Since the attribute of lighting for field leaf image is different from the lighting setup in the lab. There are many specific devices and types of equipment needed for lab images to photo-shoot the object. The equipment used to take images in the lab is a high-quality camera such as vision processing camera, machine vision camera, HD camera, inspection camera, and scientific vision camera connected to a computer to store the captured image. Special lighting system such as high-frequency fluorescent lighting is used to set the quality of lighting required in this process. In contrast, field image is still much worse than lab images because of the limitations imposed by the physical properties of the light medium (Béchet et al., 2013; NOAO (National Optical Astronomy Observatory), 2015). Field scenes are characterized by their poor visibility due to the fact that as light in the open space it gets exponentially attenuated. This result in an image that is blurred, dark and has bad contrast. Field image is insufficient from the following interference due to inconsistent lighting factors in the outdoor environment compared to photos taken in the lab. However, current technology and real-time image processing field image are widely used. The disadvantages of field images can be overcome by applying image enhancement techniques to improve the quality of field images. Therefore, field leaf images can hardly be used without any image processing technique. The low quality of field leaf image involved two different problems: image restoration and image enhancement. Image restoration has commonly been defined as the modification of an observed image in order to compensate for defects in the imaging system that produced the observed image (Lehtinen et al., 2018; Vyas et al., 2018b, 2018a). Image enhancement entails operations that improve the appearance to a human viewer, or operations to convert an image to a format better suited to machine processing (Alers et al., 2010; Saleem et al., 2012; Shukla, 2017). Both methods do not rely on any physical model of the field leaf image formation. Image enhancement aims to make the image more aesthetically pleasing through subjective criteria without relying on a complex mathematical model. Because image restoration requires many model parameters that extremely variable depends on the target's spatial position and field constitution. Consequently, it can be difficult to use in real field situation. Therefore, this research focuses on dealing with the field leaf image enhancement and not on image restoration. In the literature, there have been several techniques to enhance improve the visibility of different type of image (Hasikin & Isa, 2012b; Hitam et al., 2013; Mohammed Salih et al., 2018; Singh & Patel, 2018; Zheng et al., 2017a). The image enhancement problem can be solved by using multiple images (Barbedo et al., 2016), specialized hardware (Pérez et al., 2014) and by applying suitable enhancement technique (Chourasiya & Khare, 2019). Despite their effectiveness to enhance field leaves images, these strategies have demonstrated several important issues that reduce their practical applicability. First, the special equipment of imaging is difficult in practice (e.g., range-gated laser imaging system is hardly applied in real environment scene). Second, multiple input images of the same scene taken in different environment conditions are required, which is difficult to get. In this research work, we introduce a framework that is able to enhance field leafs image based on fusion image enhancement methods. Unlike the conventional method, our framework does not require multiple images and special equipment.

1.4 Aim and Objectives

The main aim of this research is to improve the quality of field leaf image via several methods of image enhancement. In order to achieve the aim, there are several objectives that need to be meet, which are:

1. To study image enhancement methods that suitable for leave field image.
2. To increase the quality of the field image using contrast enhancement method.
3. To construct a sequential framework for improving the quality of field image.

1.5 Research Scope

The field leaf image is a low-resolution image which low quality, blurred, noisy and low contrast. Therefore, this research aims to improve the quality of field leaf images by applying image enhancement techniques to enhance the contrast. Increasing the contrast on these images will enhance the features, and a combination of several techniques can improve the various elements on the image. Furthermore, this research also compares the performance of the methods in global and local-based. The scope of this research is categorized in data collection and data analysis as below:

Data collection:

1. The database used for this research isLeafsnap.com. Leafsnap dataset contains of 23,147 lab images and 7,719 field images. In this research, we only used 100 field images to be processed and 100 lab images as the benchmark.

2. A new field leaf image dataset is created. The field leaf images are captured using three types of smartphones: iPhone 5, Lenovo A5600 and mi A2 dual camera. The type of leaf image is the leaves of a species of shrubs that are captured randomly at the research site. The camera specifications of these smartphones are described in section 3.3.4.

3. The procedure of capturing a field leaf image is one leaf with a white background in the outdoor environment using the above devices described in section 3.3.2.

4. The number of field leaf images in the new dataset is 100 images.

Data analysis:

All data obtained from each experiment were stored and used for comparison of contrast change results. These data were also compared between different enhancement methods. This data analysis was performed to assess the degree of contrast change after the image enhancement process. The contrast level between the data obtained from each technique was also compared. Finally, the results of this study were confirmed by subject matter experts to ensure which methods are more effectively used in image enhancement.

1. The results from the enhancement process are compared with the benchmark lab images in the Leafsnap dataset.

2. The evaluation is based on Contrast (C), Contrast Difference (CD), Contrast Improvement Index (CII), and Peak-Signal-to-Noise-Ratio (PSNR) from the preliminary experiment.

3. The results from the research are validated by four agriculture expertise. The expertise observes and compares the existing and proposed framework towards the field leaf image quality. This process is to verify the advantages of this image enhancement method can be acceptable.

1.6 Research Questions

i. RQ1: How the enhanced CLAHE method can improve contrast in field images?

ii. RQ2: Is Fuzzy set approach can effectively determine the brightness for both local and global regions of field image.

iii. RQ3: Can the proposed fusion approach of the CLAHE-based image enhancement method with Fuzzy set theory accurately increase the quality of contrast and brightness of field images similar to lab images?

1.7 Research Methodology and Approach

i. Image acquisition

Leaf images of the various plant will be used for this research. There will be two stages of image acquisition. The first stage is using the field image from Leapsnap, which is the image collection is from the smartphone in any background environment. This type of leaf image is known as a field image. The second stage is to capture dataset collection using different devices at research area MARDI.

ii. Original field image as a benchmark.
The Original input field image series will be the benchmark in evaluating the enhanced field image. Therefore the values of contrast and brightness of these images will be collected.

iii. Linear Fusion Approach

a) CLAHE

CLAHE image enhancement will be applied to every field image. This is to reduce the noise implication in the field image. Followed by Unsharp Masking enhancement to enhance the image's high frequency elements and enhance the leaf veins.

b) Fuzzy set theory

At the same time, Fuzzy set theory will be applied to the same field images to determine the brightness membership function for gray levels in the images.

c) Fusion Method

Fusion techniques can improve the quality and increase the accuracy of these field images in image processing. Image enhancement using the fusion method will provide a more informative input image.

1.8 Research Achievements

In this research, a new framework of image enhancement using fusion techniques of CLAHE-based and Fuzzy theory is created to improve the quality of leaf field images. This framework is significant as it helps to analyse the leaf that potentially has been crop. This initial image processing stage of field leaf image can lead to a better decision in analysing or categorizing leaf disease to improve the production of the agriculture field. This image enhancement framework proved that field images could produce better quality and contrast stretching when using suitable image enhancement techniques. This framework can be used as the initial stage for future research before further image processing is executed for plant disease classification issues.

1.9 Thesis Outline

Chapter 1 (Introduction) introduces the topics relevant to the research field on image and image enhancement through motivation. The subject matter and problem being studied were elaborated, the importance and validity of research were indicated in this chapter. The hypotheses to be tested and the research objectives and scope to be attained were set out. The fundamental concepts related to image enhancement, categorization, and performance criteria are also briefly discussed.

Chapter 2 (Literature Review) discusses the literature survey on the existing work done in the digital field Image enhancement. This is a base for the experimental and analytical sections of the research. Subsequently, various image enhancement techniques like CLAHE-based, unsharp masking, fuzzy theory set, histogram equalization, and many more are reviewed. The quality factors of field image and lab image comparison have also been discussed. This literature review explained how it relates to the topic and showed why it is needed to do image enhancement. Furthermore, reviews about the enhancement methods are presented. Then, the existing enhancement frameworks also have been discussed.

Chapter 3 (Research Methodology) introduces the proposed research framework. Besides that, image acquisition and pre-processing also have been discussed in this chapter.

Chapter 4 (Image Enhancement) discusses how the hypothesis has been demonstrated by applying a new fusion proposed method and show how the technique has been improved the image quality by enhancement techniques. The discussion here starts with interpreting the results outwards to contextualize these findings in the image enhancement techniques. The discussion section evolved the solution between the result and theories of this research. This chapter contains a detailed of description how each process in methodology been applied. The materials used in this research are the dataset from the online repository Leafsnap and a new data collection from various types of mobile devices. The experimental designs and methods used to achieve the study's stated objectives have also been discussed in this chapter in detail and concisely. Both datasets were enhanced using enhancement techniques, and all the result values were recorded to be compared to the original input image.

Chapter 5 (Results and Discussion) this chapter provides a discussion of research employment and result like Contrast Different (CD) and Contrast Improvement Index (CII), and Peak-Signal-Noise-Ratio (PSNR) for evaluating the performance of the proposed work. The result of the proposed work based on the fusion method, the CLAHE-based method for image enhancement, has been described in detail in this chapter. The result is shown for different quality of output images and various contrast improvements for image enhancement. Also evaluated image quality of global description and local description value for other patches size of the image is evaluated. Finally proposed work is compared with the existing work using the CLAHE-based method done by previous researchers. This chapter covers the proposed algorithm for field image enhancement.

Chapter 6 (Conclusion and Future Work) This chapter restates the research and summarizes the main objective of the proposed method for image enhancement. The conclusion elaborates the image quality before and after the proposed fusion method been applied. This chapter emphasizes the research findings and generalizes their importance. The recommendation of the proposed work and future direction of research in image enhancement is discussed in this chapter.

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