Classical and Fuzzy Based Image Enhancement Techniques for Banana Root Disease Diagnosis: A Review and Validation

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Abstract

A vital step in automation of plant root disease diagnosis is to extract root region from the input images in an automatic and consistent manner. However, performance of segmentation algorithm over root images directly depends on the quality of input images. During acquisition, the captured root images are distorted by numerous external factors like lighting conditions, dust and so on. Hence it is essential to incorporate an image enhancement algorithm as a pre-processing step in the plant root disease diagnosis module. Image quality can be improved either by manipulating the pixels through spatial or frequency domain. In spatial domain, images are directly manipulated using their pixel values and alternatively in frequency domain, images are indirectly manipulated using transformations. Spatial based enhancement methods are considered as favourable approach for real time root images as it is simple and easy to understand with low computational complexity. In this study, real time banana root images were enhanced by attempting with different spatial based image enhancement techniques. Different classical point processing methods (contrast stretching, logarithmic transformation, power law transformation, histogram equalization, adaptive histogram equalization and histogram matching) and fuzzy based enhancement methods using fuzzy intensification operator and fuzzy if-then rule based methods were tried to enhance the banana root images. Quality of the enhanced root

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images obtained through different classical point processing and fuzzy based methods were measured using no-reference image quality metrics, entropy and blind image quality index. Hence, this study concludes that fuzzy based method could be deployed as a suitable image enhancement algorithm while devising the image processing modules for banana root disease diagnosis.

Introduction

The ability of plants to grow and give healthier growth and sustainable yield of a plant is directly decided by the root system. It is therefore essential to analyze the root part of a plant to diagnose disease infection in its earlier stage and to trace out the possible reasons of low productivity. Normally for diagnosis of root infestation, farmers send the root samples to subject matter specialists for inspection. The specialists diagnose root infestation and its intensity by visual examination followed by lab analysis. However, it is difficult for growers to reach the specialist for diagnosis and advisory service at all times. Secondarily, online expert systems are made available from last decade which provides online advices and solutions for infected crops where the affected root images are displayed. Growers has to compare the standard image symptom with their field systems to get advises but sometimes it might be interpreted in a wrong way. Devising an objective method such as image processing technique can prevent these complications. Thereby root abnormalities could be automatically identified to reduce human error and to have an accurate interpretation.

Over the past few years, several researchers have evaluated the capabilities of image processing algorithms in agriculture sector for addressing various issues such as fruit quality analysis, plant species identification, precision farming, remote sensing, weed recognition and disease diagnosis (Surya prabha and Satheeshkumar, 2015; Surya prabha *et al.,* 2014). Plant diseases are great menace for farmers as it reduces both quality and quantity of the crops productivity. Therefore awareness among farmers has been increased to diagnose the disease infection in its earlier stage. Camargo & Smith reported an image processing algorithms to enhance, segment and extract features from the images of leaf diseases of cotton plants (Surya prabha *et al.,* 2014; Camargo and Smith,

2009a). Camargo and Smith (2009b) also described image processing based algorithm to segment and extract diseased region from the images of banana leaf which enabled to identify diseased region even when that region was represented by a wide range of intensities. Besides, several authors have reviewed the possible methodologies and procedures of image processing technique to detect the diseases of crop plants (Surya prabha *et al.,* 2014). However, most research pay attention on analyzing the foliar diseases or symptoms. The diagnosis of plant root disease symptoms using image processing technique was not attempted earlier.

Success of root image processing algorithms exclusively depends on the quality of images. Traditionally roots were washed and cleaned thoroughly to make sure that the acquired images are of a good quality (Smit *et al.,* 2000). Of late, researchers started to use real time root images as such without staining while disease diagnosis. Images of root captured from real time environment are prone to more noises, dust and illumination. Image enhancement module of image processing plays a key role to remove unwanted information of real time images. Hence, image processing algorithms that are to be developed for the purpose of root analysis should be initiated by enhancement module to improve the image quality.

Image enhancement is foremost basic step in image processing application. It is used to improve the image quality so as to make it clearly understandable for machine and human perception (Lindenbaum *et al.,* 1994; Chen *et al.,* 2019). Quality of an image determines the accuracy of information retrieval and interpretation from an image. It is therefore essential to improve the image quality to its highest standard for better perception. Generally, enhancement of image quality can be achieved either by reducing the noise or by adjusting the contrast or by modifying the brightness in an image. It does not modify

the inherent nature of image but it modifies only the dynamic range of pixels which ascertains the smallest and highest intensity value in an image (Zhuang *et al.,* 2017). Two main category of image enhancement techniques are spatial and frequency methods (Surya prabha *et al.,* 2013). In spatial domain, images are directly manipulated using their pixel values and alternatively in frequency domain, images are indirectly manipulated using transformations. The term spatial is a representation of image plane; comprising of intensity values for each and every pixel in an image. So, this method operate directly on each pixel values and these values are enhanced by performing mathematical manipulations on individual pixels without depending on other pixels and the methods are termed as point processing methods. Image negative, power law methods and logarithmic methods are some of the examples of point processing spatial methods. If each pixel value in an image is enhanced with the support of its neighbouring pixel values, then the methods are termed as neighbourhood processing methods. Mean filtering, median filtering and Gaussian filtering are some of the examples of neighbourhood processing methods.

Image enhancement is an important research field where numerous new techniques are found in the literature but no method can claim that it is best for all type of images and applications (Starck *et al.,* 2003; Hiary *et al.,* 2017)). Similar to image segmentation, image enhancement methods are also application specific in nature and is therefore challenging to choose a relevant enhancement technique (Grigoryan *et al.,* 2019). Hence, there is high demand for image enhancement algorithms which lead to the expansion of more application specific enhancement algorithms. In this paper, different enhancement methods available in the classical point processing methods and fuzzy based methods are discussed in detail and these methods are applied over root images to identify the suitable enhancement method for possible application in banana root disease diagnosis. The performances of different image enhancement methods over root images were evaluated and compared using no-reference image quality metrics such as entropy and blind image quality index.

Classical Point Processing Methods
It is a simpler and easier technique to enhance the image quality by doing pixel-by-pixel manipulation in an image. In point operation, a mathematical equation or operation is applied over each and every pixel point expressed as,

$$A(s,t) = T[B(s,t)] \qquad ...(1)$$

where, 'B(s,t)' is an input image and 'T' is a point operation that is applied over each point in an input image to result with an enhanced image 'A(s,t)'. This technique again is broadly classified into two categories namely, gray level transformations and histogram processing (Gonzalez *et al.,* 2010). Mapping of each pixel value in an input image to a pixel value in an output image using a transformation function is termed as intensity or gray level transformation. Mapping the number of pixel occurrences for a particular intensity value in an image is termed as histogram. Manipulation performed on histogram using a discrete function is termed as Histogram Processing.

Intensity Transformation
Intensity transformation, also known as gray level transformation, is a function used to map a pixel value in an input image to a new pixel value in the output image using transformation function. These gray level transformations are either linear or non-linear in nature. In linear gray level transformation, it uses a linear function for mapping pixel values at same location in the images. In non-linear gray level transformation, it uses a non-linear function for mapping the pixel values. Image negatives and contrast stretching are some of the examples of linear gray level transformations. Logarithmic transformation and power law transformations are some of the examples of non-linear gray level transformations. These intensity transformations are not performed directly in RGB image color space and during manipulation, the input image in RGB color space is converted into gray scale color space as in Figure 1 (a & b). Standard intensity transformation functions used in image enhancement are discussed in detail in this section.

Fig.1: (a). Original input image, (b). grayscale image of (a)

Logarithmic Transformation

Logarithmic transformation is commonly used for the purpose of compressing or expanding the dynamic series of pixels in the light or dark regions of an image as in Figure 2(a). Hence, it is required to map lower intensity value with higher range of grayscale value and higher intensity value with lower range of grayscale values. Pixel values in an image are transformed or replaced using logarithmic value of each pixel using the formula,
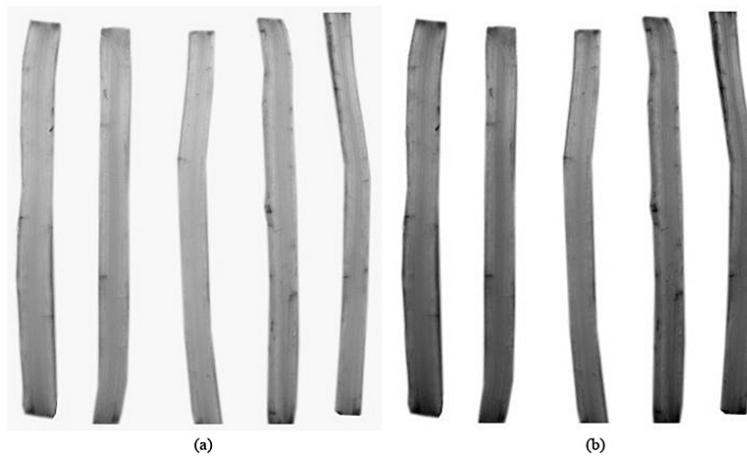
$$x = c * \log(1+a) \qquad ...(2)$$

Fig.2: Output of (a) Logarithmic transformation, (b) Power law transformation

where 'c' is a scaling constant used for image quantization and 'a' is an intensity value of the original image (I) at a point (m,n). The increase in constant value increases the image brightness. Therefore it is essential to choose appropriate constant value for enhancement to avoid ill effects like blurness. The numeric value '1' is added in the calculation of scaling factor so as to avoid problems in situations where log value is undefined.

Power Law Transformation

Power law transformation is an alternative to logarithmic transformation. It raises the pixel values in an image to a fixed power and is calculated using,

$$K(s,t) = c(I(s,t))^{\gamma} \qquad ...(3)$$

where 'K(s,t)' is the enhanced image, 'I(s,t)' is an input image with 'c' and 'γ' are positive constants.

The constant 'c' is used for scaling purpose and 'γ' is the exponent used to improve image contrast.

If gamma value (γ) has value larger than 1 then it improves the image contrast of light region in an image otherwise it improves the contrast of dark region in an image. This method is useful to manipulate the contrast of an image for general purposes as in Figure 2(b). Several image capturing

devices, printers, scanners and monitors uses the concept of power law for gamma correction which is a correction required on the output of any of these device for higher display accuracy. Gamma correction is very much useful for solving the issue of non-linear relationship between voltage, considered as input, and intensity, considered as output, in a monitor display.
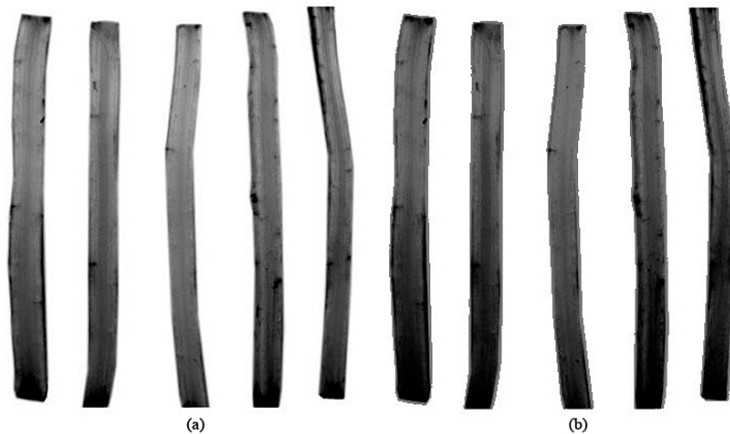
Fig.3: Output of (a) Piecewise Linear Contrast Stretching, (b) Histogram Equalization

Piecewise Linear Contrast Stretching

This is a commonly used piecewise linear function method where the intensity level range of an image is expanded for normalization and thereby contains dynamic range of value in the resultant output image as in Figure 3(a) (Gonzalez *et al.,* 2010). The input requirement is more in this method when compared with other gray level transformation methods where contrast stretching is given by,

$$K(s,t) = \left(I(s,t)\text{-}C\right)\left(\frac{(x\text{-}y)}{(u\text{-}v)}\right) + s \qquad \text{...(4)}$$

where 'K(s,t)' is the output image, 'I(s,t)' is the input image with four input values 's', 't', 'u' and 'v'. Values of 'x' and 'y' represent the upper and lower limits of the pixel range that are in use for quantization i.e., x = 255 and y = 0 for an 8-bit image. Values of 'u' and 'v' represent the maximum and minimum pixels which are actually present in the image. The value of 'u' and 'v' is ascertained from input image histogram.

Histogram Processing

Histogram is used to plot the number of frequently occurring pixel intensities in an image. Horizontal

axis of histogram represents information related to the intensity values in a range of [0–255] for 8-bit image and vertical axis represents information related to the frequent occurrences of each intensity value within an image (Gonzalez and Woods, 2011). Enormous information is gathered through histogram as it provides global information about the image properties including its appearance and texture. In histogram processing, contrast of an image is enhanced by doing mathematical manipulations over the histogram. It modifies the active range of pixel intensities in an image using discrete transformation function. It is used in different modules of image processing like image enhancement, image segmentation, image description and image compression and is mainly helpful in processing the real time images. Histogram equalization, histogram matching and adaptive histogram equalization are some commonly available histogram processing methods.

Histogram Equalization

It is a familiar method used to enhance the image contrast by spreading the intensity values evenly in

an image. Complete automatic process with simple computational task is the major advantage of this method. The result of enhanced output image is purely dependent on the histogram of input image. It considers variable assigned to intensity values of input image either as continuous or discrete variable. In this method, the acquired input image is remapped or transformed into a new image i.e., the output image using the mapping function,

I=f(A)   ...(5)

where 'A' is the intensity values of input image and 'I' is the intensity values of output image. 'f(A)' must be single value and must increase monotonically which are the major conditions that determine the validity of mapping. It uniformly distributes the histogram of input image to obtain an enhanced output image. This mapping is done using probability density function which assures that the histogram of output image is equally distributed as in Figure 3(b).

Adaptive Histogram Equalization
Generally, Histogram equalization method is global in nature and is suitable for situations where the entire image region needs to be enhanced. It lacks to perform better for local region enhancement in an image. Histogram of local regions must be manipulated to enhance the required local region in an image. This process is achieved by adaptive histogram equalization where the different regions in the image are manipulated through regions local properties. Sliding window approach is a simple, easier and common method used to enhance the image using adaptive histogram equalization. It breaks the image into different small blocks or tiles or windows and these blocks use outer window to obtain the required histogram equalization. This method is very much successful and helpful to increase the contrast of local regions as in Figure 4(a). There is a higher probability for over increase in contrast and occurrence of block artifacts in an image. To avoid these artifacts, the outer window size is increased comparatively to the inner window size. In order to restrict the increase in contrast value within certain limit, Contrast limited adaptive histogram equalization method is expanded from the adaptive histogram equalization method for better and efficient enhanced result.
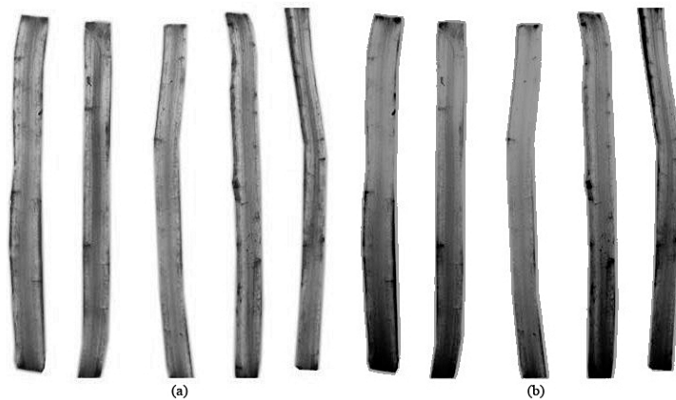
Fig.4: Output of (a). Adaptive Histogram Equalization, (b) Histogram Matching

Histogram Matching
Histogram Matching or Histogram Specification is based on the same principles of histogram equalization. Unlike histogram equalization where the target histogram distribution is automatic, in this method, the target histogram distribution is user-specific. This technique is suited in the situations where the user has knowledge or idea about the regions in input image that require enhancement.

Required histogram shape is specified manually either by a mathematical function or from an existing reference image with required histogram distribution as in Figure 4(b).

Fuzzy Image Enhancement Methods
The developments and innovations in the concept of fuzzy logic paved its way for applications in image processing. This concept of fuzzy logic was initially

integrated into image processing by researchers like Prewitt, Pal *et al.,* and Rosenfeld (Chaira and Ray, 2016). The pixel values which are the key constituent in an image are uncertain, imprecise and indeterministic. So during the development of an automated system for banana fruit quality analysis, the interpretations based on the crisp set of pixel values might mislead. So the use of fuzzy logic by considering pixel values as fuzzy in nature would produce accurate, certain and reliable result. The fuzzy image processing is considered as a compilation of varied fuzzy approaches with three main stages namely, fuzzification, modification of membership values and defuzzification. Fuzzy set concept is applied in numerous modules of image processing like image enhancement, image segmentation and image retrieval. In image enhancement, contrast of an image is adjusted by modifying the membership values to transform the original image into enhanced image (Pal and King, 1981). So for this purpose of adjusting and transforming the pixel values membership function is applied. There are numerous fuzzy based enhancement methods available in literature using fuzzy intensification operator, fuzzy if-then rules and fuzzy expected value and so on. In this section the commonly used fuzzy based enhancement methods

using fuzzy intensification operator and fuzzy if-then rules are discussed in detail.

Image Enhancement using Fuzzy if-then Rules
Fuzzy rule based methods are very useful even for problems that are non-linear in nature. It is tedious to define deterministic criteria for enhancing an image. This task has been made simpler using the fuzzy approach. It is based on the simple classical rule system – "if (specific condition) then (specific action)". Specific rules are defined for the pixels in an image for enhancement (Li and Yang, 1989). These rules or conditions are formed by considering the gray level pixel value in an image. Based on these conditions decisions are made individually and then it is combined together to make a final decision. In a simple fuzzy if-then system, the maximum, minimum and mid gray levels of an image is calculated. As a fuzzification process, the membership values are assigned for the different (dark, gray and bright) regions of an image. Then a fuzzy inference is done to modify the membership functions in an image. As a consequence of inference mechanism, the pixel values of different regions with dark, gray and white is transformed into black, gray and white. Then using the inverse of fuzzification, the result of inference system is defuzzified (Figure 5.a.).
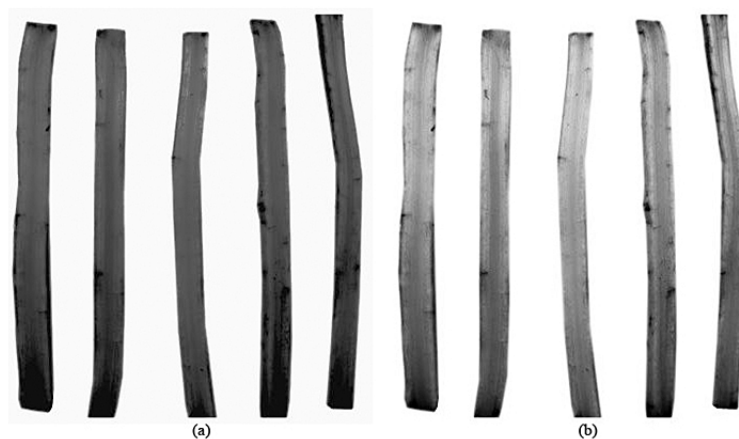

Fig.5: Output of (a). fuzzy if-then rule, (b) fuzzy intensification operator

Image Enhancement using Fuzzy Intensification Operators
In this fuzzy method of image enhancement, contrast of an image is improved by using fuzzy intensification operator (Figure 5.b.). As this method

depends mostly on the gray levels of an image, the gray scale image is considered as a single fuzzy set (Hanmandlu *et al.,* 2003; Hanmandlu and Jha, 2006). The membership function for this fuzzy set is defined as

$$\mu_{xy} = [1 + I_{max} - I_{min} / d]^e \qquad ...(6)$$

where "I_{max}" and "I_{min}" are the maximum and minimum gray levels in an image, 'I', 'x' and 'y' are the pixel co-ordinate points for image location (x,y), 'd' and 'e' are the fuzzifiers used to control the uncertain amount of grayness in an image.

In this method, pixel values are darker when the membership value is less than 0.5 and pixel values are brighter when the membership value is greater than 0.5. The main objective of this method is to reduce the fuzziness in an image (Surya prabha and Satheeshkumar, 2016a). Image with low contrast has more fuzziness in the image fuzzy set and to increase the contrast of image, the fuzziness must be reduced. So the intensification operator for the set is defined as

$$\mu'_{xy} = \begin{cases} 2.[\mu_{xy}]^2, & 0 \le \mu_{xy} \le 0.5 \\ 1 - 2.[1 - \mu_{xy}]^2, & 0.5 \le \mu_{xy} \le 1 \end{cases} \qquad ...(7)$$

After modifying the membership function, the modified values are transformed into the spatial domain using an inverse function.

$$I'_{xy} = I_{max} - d[(\mu'_{xy})^{-\frac{1}{e}} - 1] \qquad ...(8)$$

Performance Evaluation
The root images were collected from 20 banana plants at Sirumugai village, Coimbatore District, Tamil Nadu, India. The root samples taken from banana plant were split vertically into two halves in such a way to visualize any damage or infection on roots as per INIPAB root damage assessment guidelines (Carlier *et al.,* 2003). Performance of the spatial based enhancement methods was evaluated over ten real time banana root images. Under classical enhancement methods, different point processing methods such as contrast stretching, lograthmic transformation, power law transformation, histogram equalization, adaptive histogram equalization and histogram matching; and fuzzy based enhancement methods using fuzzy intensification operator and fuzzy if-then rules were used to enhance the banana root images.

The enhanced output attained through different classical point processing methods and fuzzy based methods must be analyzed and evaluated.

The performance of enhancement methods are assessed either by using qualitative or quantitative assessment methods. The qualitative method of evaluation is based on human judgments and faces challenges like human bias, cost and time consumption and unreliability. So it preferred to use the quantitative method of assessment for evaluating the performance of different enhancement methods. As the data set is real time in nature and has no ground truth image, no-reference image quality method is suitable for assessment. Shannon entropy and blind image quality index are the two no-reference image quality metric used in this paper.

Entropy
Shannon entropy measures the uncertainty or information in an image (Surya prabha and Satheeshkumar, 2016b). It is a classical method of evaluation used for no-reference image data sets. The concept of this method has been taken from information theory and is calculated using,

$$E = -\sum_{x=1}^{a} e_x \log e_x \qquad ...(9)$$

where 'e' denotes pixels frequency and 'a' denotes intensity value of pixel. Entropy with lower value have less uncertainty in an image and entropy with higher value have more uncertainty in an image.

Blind Image Quality Index (BIQI)
Blind image quality assessment measures the anisotropy value in an image using renyi entropy and normalized pseudo-Wigner distribution (Gabarda and Cristobal, 2007). BIQI calculates the expected entropy variance value based on the spatial frequency distribution (pixel-by-pixel) from a set of predefined directions in an image and generates entropy histogram. The spatial frequency distribution is calculated as a discrete approximation for a probability density function. The discrete approximation is calculated using the Wigner distribution for the selection of directionality for variance calculation. Hence, the normalized Pseudo-Wigner distribution is used for extracting the spatial frequency distribution in an image.

The renyi entropy is defined for discrete space-frequency distribution F[x, y] as

$$R = \frac{1}{1-\alpha} \log_2(\sum_x \sum_y F^\alpha [x, y]) \qquad ...(10)$$

where 'x' is the spatial variable and 'y' is the frequency variable and in general 'α' value of 2 is recommended for the space-frequency distribution.

The variance value calculated from renyi entropy is considered as the directionality function and is used as anisotropy indicator. This method is very much useful to assess the quality of real time images. Blind Image Quality Index (BIQI) with higher value indicates the better performance of the method and with lower value indicates poor performance of the method.

Analysis of Data Sets

Entropy and BIQI was calculated for the enhanced images achieved through different enhancement techniques. The data sets of Entropy and BIQI obtained from contrast stretching, logarithmic transformation, power law transformation, histogram equalization, adaptive histogram equalization,

histogram matching, fuzzy intensification operator and fuzzy if-then rules methods were statistically analyzed. Analysis of variance (ANOVA) with Tukey's HSD multiple range tests was used to compare the significance of datasets of different enhancement methods. The software used for statistical analysis was IRRISTAT version 92 developed by International Rice Research Institute Biometrics unit, Philippines (Panse and Sukhatme, 1989).

Results and Discussion

The results of Entropy and BIQI values for different image enhancement methods are shown in Figure 6 and Figure 7. The fuzzy if-then rules methods recorded less entropy values (3.89 – 4.66) and high BIQI values (0.025 – 0.046). Adaptive Histogram Equalization technique recorded the high entropy values (4.62 – 5.38) where as Logarithmic Transformation recorded the least BIQI values (0.003 – 0.010).
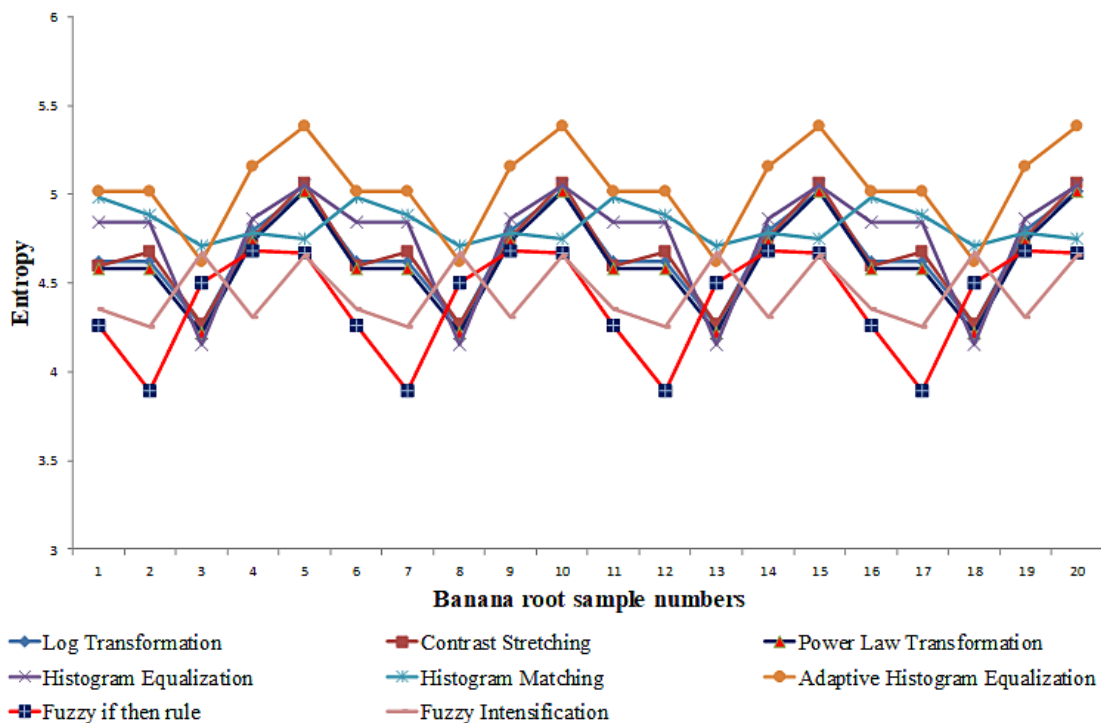
Fig.6: Distribution pattern of Entropy values of different image enhancement techniques
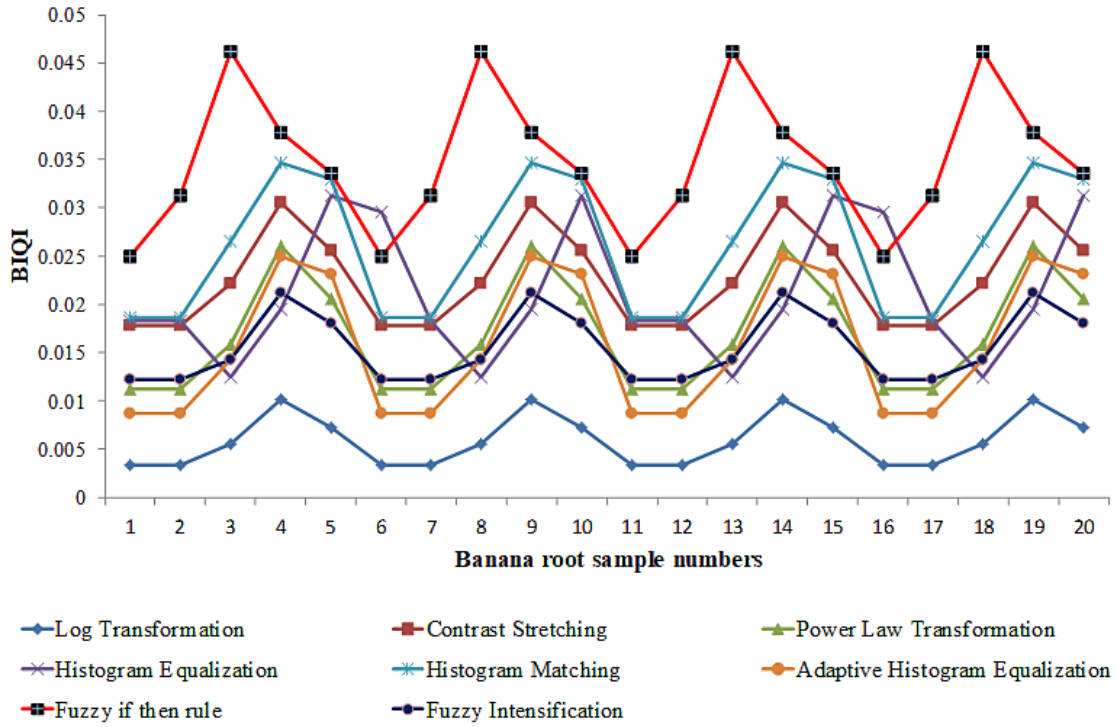
Fig.7: Distribution pattern of BIQI values of different image enhancement techniques
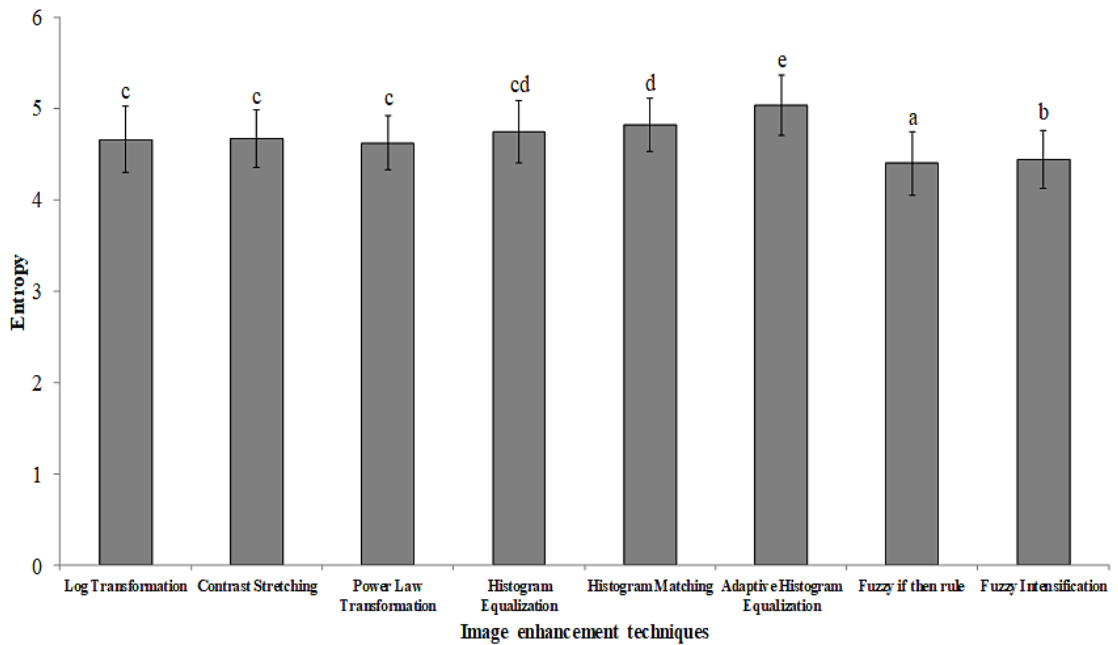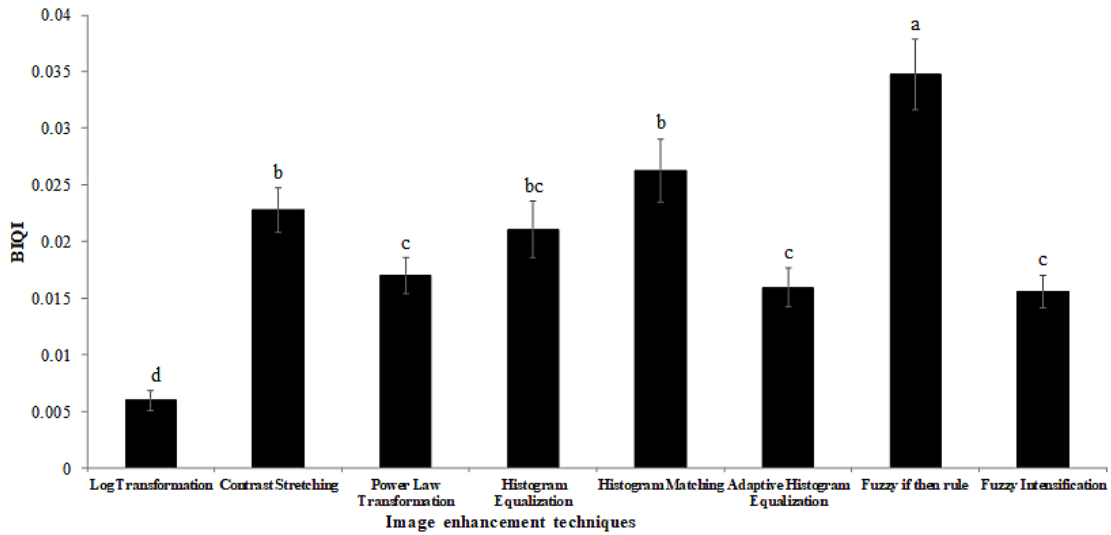

Fig.8: Comparing the Entropy values (±SEM) of different image enhancement techniques by ANOVA. Bars followed by the same letter do not differ significantly according to Tukey's HSD multiple range test (P<0.05)
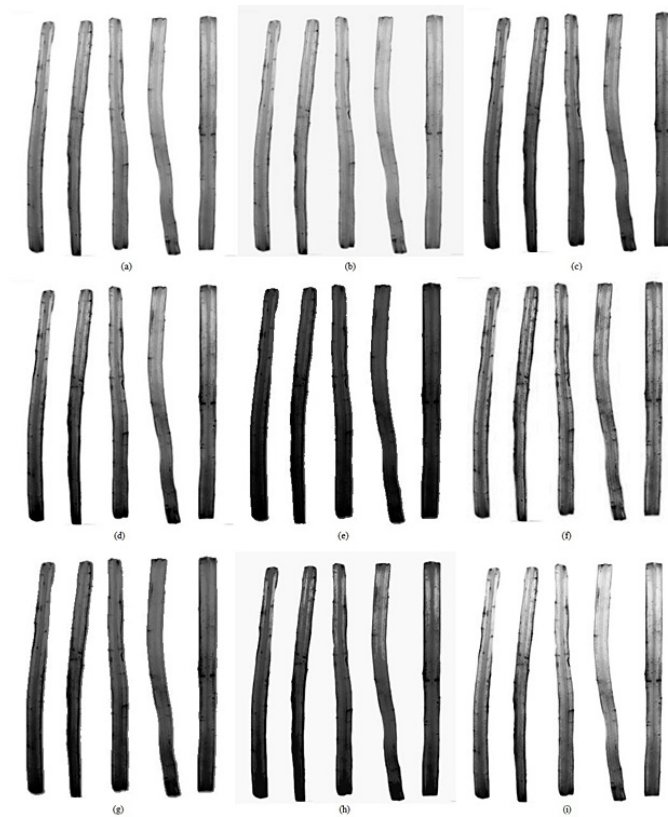
Fig.9: Comparing the Entropy values (±SEM) of different image enhancement techniques by ANOVA. Bars followed by the same letter do not differ significantly according to Tukey's HSD multiple range test (P<0.05)

Fig.10: Comparing the Entropy values (±SEM) of different image enhancement techniques by ANOVA. Bars followed by the same letter do not differ significantly according to Tukey's HSD multiple range test (P<0.05)

The average Entropy and BIQI values for different image enhancement methods are shown in Figure 8 and Figure 9. Statistical analysis of variance revealed that there was significant differences among the eight different image enhancement techniques in entropy ($F = 7.30$; $df = 7, 72$; $P \leq 0.001$) and BIQI ($F = 19.7$; $df = 7, 72$; $P \leq 0.001$). Entropy is significantly lower (4.40) in fuzzy if-then rules techniques than all other methods evaluated. Adaptive Histogram Equalization techniques had significantly high mean entropy values (5.03). BIQI value was lowest for the Logarithmic Transformation (0.005). BIQI value was significantly higher for fuzzy if-then rules method (0.347). The results clearly indicated that the fuzzy if-then rules method is best method among different image enhancement techniques to enhance the banana root images (Figure 10).

The performance of these image inhancement methods with standard data set (CSIQ) were also compared in our earlier study and showed that fuzzy if-then rules method is better than other methods (Prabha, 2018). Also our earlier study demonstrated that performance of image enhancement by fuzzy if-then rules method improved the classification accuracy of leaf disease image sets significantly.

Conclusion
Numerous algorithmic approaches are available to modify and adjust the acquired images to make them have better human interpretation and visual understanding. Plant root disease diagnosis using real time images is one of the thrust areas in agriculture sector. This paper reviewed various spatial domain image enhancement techniques existing in literature that can be exploited for improving quality of root images. This study compared different classical point processing methods (contrast stretching, logarithmic transformation, power law transformation, histogram equalization, adaptive histogram equalization and histogram matching) and fuzzy based methods for real time banana root images. Performance of all methods was evaluated using entropy and blind image quality index. Results revealed that fuzzy based if-then rule method is performing better to improve the banana root image quality. This technique is effective in eliminating the noise, preserving image boundaries and fine details. Hence enhancement of banana root images by fuzzy if-then rule based method will improve the accuracy for further steps of image segmentation, feature extraction and classification while devising the banana root disease diagnosis process.

Conflict of Interest
The authors do not have any conflict of interest.

References

1. Camargo, A., Smith, J.S. (2009). An image-processing based algorithm to automatically identify plant disease visual symptoms. *Biosyst. Eng.,* 102, 9-21.

2. Camargo, A., Smith, J.S. (2009). Image pattern classification for the identification of disease causing agents in plants. *Comput. Electron Agric.*, 66, 121–125.

3. Carlier, J., De Waele, D., Escalant, J., Vezina, A., Picq, C. (2003). Global evaluation of *Musa germplasm* for resistance to *Fusarium* wilt, *Mycosphaerella* leaf spot diseases and nematodes: Performance evaluation. INIBAP *Technical Guidelines.p.* 57. Montpellier, France: INIBAP.

4. Chaira, T., Ray, A.K. (2016). Fuzzy image processing and applications with MATLAB.p. 237. Finland: CRC Press. 2016.

5. Chen, Y., Yu, M., Jiang, G., Peng, Z., Chen, F. 2019. End-to-end single image enhancement based on a dual network cascade model. *Journal of Visual Communication and Image Representation*, 61, 284-295.

6. Gabarda, S., Cristóbal, G. (2007). Blind image quality assessment through anisotropy. *J Optical Soc. Am.*, 24, 32-51.

7. Gonzalez, C.R., Woods, R.E. (2011).Digital image processing. P. 976.India: Dorling Kindersley (India) Pvt Lt Publications.

8. Gonzalez, C.R., Woods, R.E., Eddins, S.L.

(2010). Digital image processing using MATLAB. P. 578. India:Tata McGraw-Hill Publications.

9. Grigoryan, A.M., Agaian, S.S. 2019. Gradient based histogram equalization in grayscale image enhancement. *In Mobile Multimedia/ Image Processing, Security, and Applications* 2019 (Vol. 10993, p. 109930O). International Society for Optics and Photonics.

10. Hanmandlu, M., Jha, D. (2006).An optimal fuzzy system for color image enhancement. *IEEE Trans. Image Process.*, 15, 2956-2966.

11. Hanmandlu, M., Jha, D., Sharma, R. (2003).Color image enhancement by fuzzy intensification. *Pattern Recognition Letters,* 24, 81–87.

12. Hiary, H., Zaghloul, R., Al-Adwan, A., Moh'd B, A. Z. 2017. Image contrast enhancement using geometric mean filter. *Signal, Image and Video Processing*, 11(5), 833-840.

13. Li, H., & Yang, H.S. (1989). Fast and reliable image enhancement using fuzzy relaxation technique. *IEEE Trans Syst. Man Cybernatics*, 19, 1276-1281.

14. Lindenbaum, M., Fischer, M., &Bruckstein, A. (1994).On Gabor's contribution to image enhancement. *Pattern Recognition,* 27, 1-8.

15. Pal, S.K., King, R. (1981).Image enhancement using smoothing with fuzzy sets. *IEEE Trans on Syst. Man Cybernatics,* 11, 494-500.

16. Panse, V.G., Sukhatme, P.V. (1989).Statistical methods for Agricultural Workers.p 359. New Delhi, India: ICAR.

17. Prabha, D.S. 201). Development of an efficient model for banana grading and crop disease analysis using optimized image enhancement and segmentation algorithms. PhD Thesis submitted to Bharathiar University, Tamil Nadu, India.

18. Smit, L.A., Bengough, A.G., Engels, C.,. Van Noordwijk, M., Pellerin, S., Van De Geijn, S.C. (2000). Root Methods:A Handbook. P. 587. Heidelberg:SpringerVerlag.

19. Starck, J.L., Murtagh, F., Candes, E.J., Donoho, D.L. (2003).Gray and Color Image Contrast Enhancement by the Curvelet Transform. *IEEE Trans. Image Process.*, 12, 706-717.

20. Surya prabha, D., Satheeshkumar, J. (2013). Three dimensional object detection and classification methods: a study, *Int. J. Eng. Res. Sci. Technol.*, 2, 33–42.

21. Surya prabha, D., Satheeshkumar, J. (2014). Crop disease identification using image processing methods, In. *Green Computing,* India:Hikey Media, pp. 174-179.

22. Surya prabha, D., Satheesh kumar, J. (2015). Assessment of banana fruit maturity by image processing technique. *J. Food Sci. Technol.,* 52(3), 1316-1327.

23. Surya prabha, D., Satheesh kumar, J., Gokulakrishnan, R. 2014. A survey on applications of image processing methods in agricultural sector. *In International Conference on Convergence Technology*, 4, 997-999.

24. Surya prabha, D., Satheeshkumar, J. (2016a). An efficient image contrast enhancement algorithm using genetic algorithm and fuzzy intensification operator. Wireless Personal Commun., DOI: 10.1007/s11277-016-3536-x.

25. Surya prabha, D., Satheeshkumar, J. (2016b). Performance Evaluation of Image Segmentation using Objective Methods. *Indian J. Sci. Technol.*, 9, 1-8.

26. Zhuang, P., Fu, X., Huang, Y., Ding, X. 2017. Image enhancement using divide-and-conquer strategy. *Journal of Visual Communication and Image Representation*, 45, 137-146.