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Study of Plant Phenotype using Image Segmentation Techniques

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***Abstract*—** The study of plant phenotype using segmentation techniques is one the leading research area in the field of agricultural technology. Plant phenotype is a technical term which is used to describe the observable characteristics of the plant like width, height, biomass, plant, leaf shape and so on. It is required in order to study about the physical characteristics of the plant like finding the area, height, width, structure of the plant and skeleton generation of the plant root etc. It is used in the field of agricultural technology to carry out various types of research. This paper explores the use of different segmentation methods in order to get efficient segmented images for the plant's shoot and root systems. The segmentation methods used are threshold segmentation, edge detection, and followed by contour segmentation on PlantCV platform. The proposed work partitions the segmentation process in four steps, where the output of each step is given as input to the next step. We use the thresholding method as a first step in plant image segmentation process to remove the background and noise in the image. This step is followed by edge detection method to remove the unwanted regions and to detect false edges in a segmented plant image. Next, the contour segmentation is used to identify the complete structure of the plant. Then from the output image obtained, features are extracted in JSON format and the segmented images acquired are stored in an output folder.

Keywords—Segmentation, Phenotype, Sobel operator, PlantCV platform, Shoot module, Root module, Contour Segmentation, Edge Detection, threshold Segmentation, Gaussian Blur, Median Blur, Region of Interest(ROI).

I. INTRODUCTION

In the area of image processing, the segmentation of an image is very important and it's a challenging process. Segmentation of image plays a vital role in partitioning a digital image into significant parts which contains common structural properties and features. The primary goal of segmentation is to modify and simplify the image representation into different representations, which is more relevant and easier to evaluate. The boundaries and objects (edges, lines, curves etc.) are identified using image segmentation. Actually, in an image assigning label to each pixel is an important process such that pixels having same label which contain particular visual aspects.

In recent years study of recognizing plant structure is a major research problem taken up by many research groups. One of the examples listed is Plant vein extraction which is considered as a significant task to identify the parts of plant structure. Evaluating and measuring the availability of plants is the fundamental botanical skill, with numerous applications, which are ranging from recognizing the plant structure to effective shape analysis. For recognising root and stem structure, plant species, flowers, leaves and the whole plant is under observation. Plant structure is said to have roughly two-dimensional in nature. Thus, it is considered as good candidate for image processing. Visually characterizing is one of the most significant aspect of plant structure for various plants, to develop a plant recognition system the study of plant phenotype segmentation is very essential.

Image segmentation is a first and foremost step/stage in the process of identifying the plant structure, sometimes the output of segmentation are not gauged properly [1]. However, the different methods used for recognising plant structure can be also being considered for plant phenotype segmentation. In the proposed work the preferred segmentation approaches are listed as threshold segmentation, edge detection and contour detection methods. This task provides an enforcement technique for different thresholding methods along with sobel edge detection to get rid of the false edges and over-segmentation in the process of segmentation.

There are several techniques to perform image segmentation. Threshold segmentation method is the simple and widely used method in the segmentation. It is one of the most popular method because it uses simple functions to remove the background and noise in the image. Widely used functions supporting Threshold segmentation are Gaussian blur, Median blur, RGB to LAB, masked and so on. The main characteristic of this segmentation is to remove the background by applying different channels to an image, such as H(hue), S(saturation), V(value), L(lightness), A(green magenta), B(blue-yellow), R(red), G(green), B(blue)[2]. And the noises in the image are reduced by changing the threshold values like 115, 135 and 128 randomly.

Edge detection is used as main preprocessing step in classifying and recognizing objects. The edges are identified based on their gray level properties and assist in acquiring their relative information. An edge is defined as the boundary between two regions with relatively distinct gray level properties. Edge detection is a segmentation method which detects the edges based on boundary objects. Based on one particular light intensity condition the classifiers are usually over-fitted. Thus, edge detectors are well known for plant classification. For changing robust illumination conditions edge detection is fairly used. The curves correspond to discontinuities in surface orientation and brightness. The boundaries of marked surface indicate a set of connected curves which is obtained by applying an edge detector to an image. To filter out irrelevant data and to minimize the quantity of processed data in plant image, sobel edge operator is used, by preserving necessary shape properties of an image. The important data about the image is present in the edge map and this edge map is obtained by edge detection algorithm. The significantly simplified original images are interpreted in successive steps. Hence, the edge detection is a very important process.

The Sobel operator helps to detect the edges of plant structure. The edges to be detected should be present at a greater distance from one another to remain unaffected by the distribution of edge of a plant structure. For data distribution the number of edges should be identical. Between each data point the accumulated metric is computed by designated edge positions and sharp edge corners, all previous lines and selected data points should have maximum value. Sometimes many edges are formed which makes it hard to identify the correct plant shape. Prior to classification of plant species the complicated background objects contained in the plant images should be eliminated.

To detect plant structure the Sobel edge detector is considered as first important algorithm in the segmentation procedure. The second algorithm used is contour segmentation which helps to remove the hidden regions for shape fitting which is followed by shape analysis. Contour segmentation is used to find the size of the object of interest and detecting it. Using the ROI (Region of Interest) boundary the objects are segmented. Firstly, the border points extracted for each object in the image are blue colored. The extracted contour points either represent the contour of single object or multiple objects. The contour of overlayed object represents inconsistent shape. If the contour is detected in the ROI then the entire object of that contour is filled with green color.

After completion of segmentation process the next task is to extract the features of the given plant structure in JSON format and to store segmented images in output folder. By using this segmented images we are checking for accuracy and performance of the system by using different matrices like energy, entropy, and UQI (universal quality index), which is shown in the observation results section(IV). This paper explains the study of plant phenotype using above mentioned segmentation techniques to obtain efficient segmented image of plant. This is further used to perform research in the field of agricultural technology. Plant phenotype refers to a quantitative description of the plant's anatomical, physiological and biochemical properties. This is one of the approaches to study about the physical characteristics of the plant like finding the area, height, width, structure of the plant and skeleton generation of the roots of plant. This proposed work is carried out using the PlantCV platform, where it contains several built-in API's (Application Program Interface) to perform phenotype segmentation activities.

This paper mainly explains the image segmentation of plant images by implementing two modules, one is Segmentation of Shoot part of the plant (above the root), and another one is Segmentation of Root part of the plant image. The complete process as shown in Figure 1 is divided into four stages namely Image Acquisition, Image pre-processing, Image Segmentation and feature Extraction.

The Figure 1 explains the plant image segmentation process, where initially user loads the input plant image into the system as a part of image acquisition step, then as a part of image pre-processing stage the input image is screened for noise in order to eliminate it. Next to obtain segmented plant image the proposed work makes the pre-processed image to undergo three segmentation methods namely threshold based segmentation, edge detection and contour detection techniques. The next stage involves feature extraction, where all the details such as height, width, structure of the plant and depth of the root is recorded in JSON format.

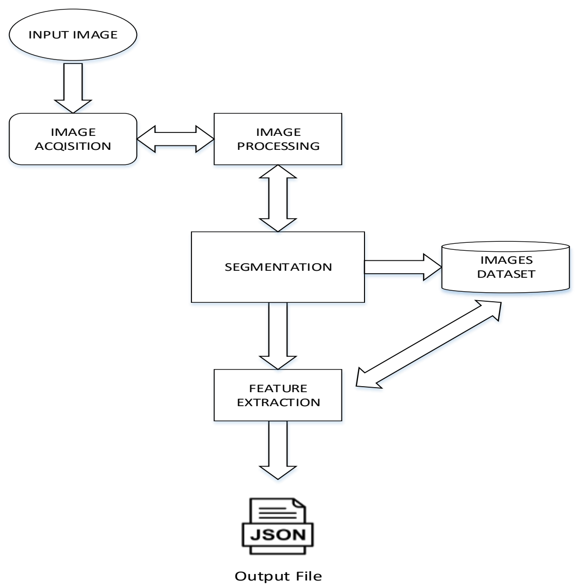

Figure 1. Steps in plant phenotype segmentation.

II. RELATED WORK

An image segmentation method is presented by V. Sivakumar and V. Murugesh for “Segmentation of a digital image using Thresholding Technique on a Noisy Image” [3]. For differentiating foreground and background using thresholding technique on an image corrupted by Gaussian noise and salt pepper noise. They tested a digital image using iterative algorithm to estimate the background information to help global thresholding approach. However, for real time plant images further improvement is necessary by observation result.

Sheetal Israni and Swapnil Jain [4] proposed an edge detection method on “Edge Detection of License Plate Using Sobel Operator”, in which sobel operator has a benefit on smoothing effect to the random noises in the digital image. If an image contains greater amount of white Gaussian noise, to get a peak value of initial derivative is difficult. Thus, sobel is an enhanced operator which point out the edges more efficiently, less sensitive to noise and helps to achieve parallelism.

The Fari Muhammad Abubakar and et.al. in [5] proposed interactive contour segmentation method for shape analysis of an image. They provide user to draw several points directly on the object boundary of the image, then the algorithm attempts to match the points on the boundary. Finally, contour model is utilized to detect the object contours on the boundary, and it is used to obtain the features of an image objects.

The study in paper [5] suggests that the different segmentation methods are used in various fields for image segmentation. In this paper we are using Threshold based segmentation, edge detection and followed by contour segmentation for the analysis of real time plant images. So, we are using thresholding methods like Gaussian and median blur effectively to remove background and noise in the image. Then by using sobel operator in edge detection we are extracting the edges of objects in an image. Next, the contour segmentation is used to determine the structure and features of the plant in the image. So, we are using this various plant segmentation methods in one environment called plantCV where it contains some built-in API’s (application program interface) to perform segmentation activities.

III. METHODOLOGY

The proposed work is divided into two modules namely Segmentation of Shoot part of the plant (above the root) and Segmentation of Root part of the plant image. Segmentation of shoot module involves study of upper part of the plant such as plant height, width and plant structure. Segmentation of Root module involves study of root part of the plant to get the information regarding root depth, width, root area and skeleton of the root. This work is carried out using PlantCV platform, which contains several built-in library functions to perform the plant image segmentation process. The entire process is divided into four stages as shown in the figure 2:

1. Image Acquisition
2. Image pre-processing
3. Image Segmentation
4. Feature Extraction

As a part of first step the user loads the plant image to the system. This is a high resolution image taken by a high resolution camera device or mobile phone. After loading the image, as a part of second step the image is pre-processed to reduce the noise in it. Then the image segmentation process is performed to obtain effective segmented plant image. Finally, after completing the segmentation process the next step is feature extraction, where all the plant details such as height, width, structure of the plant, depth of the root are recorded in the JSON or CSV file, and corresponding filtered images are stored in the output folder.

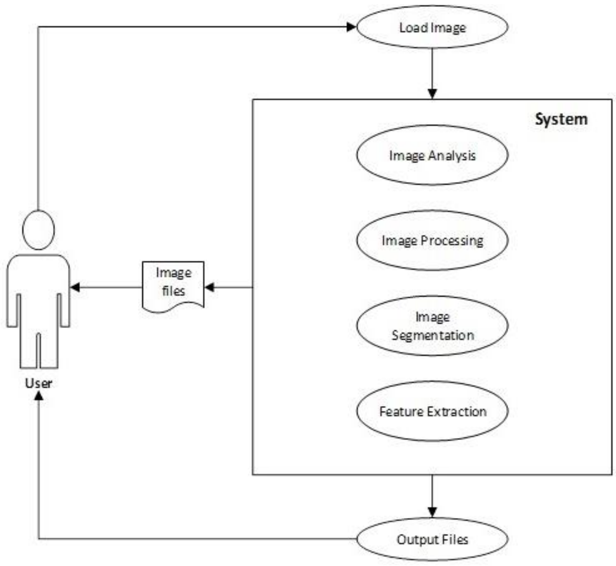

Figure 2. Work flow diagram of plant phenotype segmentation.

3.1 Image Acquisition

This stage involves loading of real-time plant images into the system, which are captured using high resolution camera device or mobile phone, they may be taken from different fields at different angles. The captured images are in PNG or JPG or JPEG format. These images can be with or without background. Here, we are considering the two types of images, one is the whole plant image including root part, another one is only root images excluding upper part of the plant in order to provide input to the corresponding module (Shoot Segmentation and Root segmentation) respectively.

3.2 Image Pre-processing

This image pre-processing stage consists of enhancement of plant image information by eliminating undesirable distortions or to re-in force certain image aspects for further processing. It employs different approaches on images like noise filtration, conversion of an image, dynamic changes in image with respect to size and form, to ensure the better quality of an image and to remove certain noise contained in it before further processing.

3.3 Image Segmentation

Image segmentation is the process of partitioning the images into different segments. The main goal of image segmentation is to group the pixels into various individual areas (regions). Attributes represented by gray levels, colour and structure are identified by the region of pixels based on their similarities.

To perform image segmentation, the proposed work explores the following segmentation techniques as shown in figure 3:

- Threshold based segmentation
- Edge Detection
- Contour segmentation

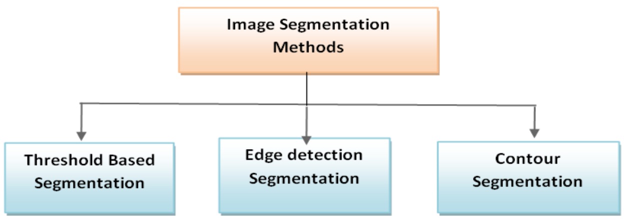

Figure 3. Types of image segmentation methods[6].

3.3.1 Threshold based segmentation

The threshold based segmentation is a method that segments the image into various regions having similar characteristics. This segmentation is used to partition the objects into distinct regions based on threshold values. So, it is known as "Threshold Segmentation". Thresholding of an image is a yet effective, simple, method or way of partitioning an image into a background and foreground. The conversion of grayscale images into binary images by isolating the objects is a type of image segmentation technique in image analysis. When high levels of contrast are present in images then the image thresholding is a most effective method.

In this process of segmentation we first threshold out the background and perform some pre-masking of the image background. The aim is to reduce foreground and background pixels as much as possible from the plant image without losing any information. The thresholding method contains some channels like B (Blue), G (Green), R (Red), B (Blue-Yellow), A (Green Magenta), L (Lightness), V (Value), S (Saturation), H (Hue). This work selects one of them for an image to perform binary thresholding task. Firstly, here the proposed work converts the Red, Green, and Blue (RGB) picture to Hue Saturation Value (HSV) colour space to extract any channel (H, S or V) which can be selected based on the user needs. Thus, this work uses 'S' or Saturation channel. In later, step some thresholded channels are combined if any region of the plant is not visible or missed in plant image. Next, the image objects thresholds are either dark or light, otherwise or in white, when thresholded channel is saturated. Again, based on lighting parameter in the image one needs to remove foreground or background in an image. A Gaussian blur and median blur methods are used to remove noise. A Gaussian blur is a linear filter; it is usually used to blur the image or to reduce noise. Gaussian blur is used to reduce the contrast and blur the edges. To reduce noise in the image median blur is used as non-linear filter. It claims that (over Gaussian for noise reduction) it removes noise while keeping edges relatively sharp. Next, the original image is converted from an RGB image to LAB ('L' (Lightness), 'A' (Green-Magenta), 'B' (Blue-Yellow) channel) colour space and here in the proposed work extracts blue-yellow channel. Blue-yellow channel from LAB colour space image is thresholded into thresholded blue-yellow channel image. Then these two binary images are joined by using logical-OR function.

Image mask is applied on original image, after merging the binary images. The purpose of applying mask is to eliminate background without loosing much information of plant structure by using simple thresholding method. After removing background mask image is obtained which helps to capture better image of the plant. Next, from masked image blue-yellow and green-magenta channels are extracted. For capturing various parts of the plant two thresholded channels are used and then they are merged with masked image. Then to fill the noise the small objects are used. For masking the masked image the obtained binary image is used. The noise reduced masked images are converted into thresholded LAB channel images, on different thresholding values like 115,135 and 128 and then combine these thresholded images. At the end we get segmented image with complete removal of background and noise without loosing any plant structure in the plant image.

3.3.2 Edge Detection

In image processing the edge detection methods are well developed techniques for detecting the edges of an object. The edge based segmentation are the methods in which value of intensity of an image changes rapidly because an intensity of a single value will not provide all information about edges. To segment the required boundary regions in edge based segmentation, the object boundary edges are detected and connected together. The basic edge detection technique to detect the edges such as sobel operator is used [7]. The threshold segmentation results removal of background in an output image but partially identifies the objects. In order to detect the objects in an image accurately next step is to use edge detection algorithm. Sobel operator is used to define edges within and around objects.

To obtain the difference between the horizontal and the longitudinal layouts respectively, the sobel operator contains two sets of 3x3 matrices, which represent transverse and longitudinal templates which are plotted with the image plane. In order to detect edges of image the following two matrices are actually used.

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

Matrix used for horizontal edge

$$G_x = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Matrix used for vertical edge

Using the equation (1) the size of the gradient is calculated by approximating both vertical and horizontal gradient of each pixel of an image.

$$G = \sqrt[2]{G_x^2 + G_y^2} \qquad (1)$$

Using the equation (2) the gradient can then be calculated.

$$\theta = \arctan(\frac{G_y}{G_x}) \qquad (2)$$

If the image contains a longitudinal edge then angle Θ is considered as zero and also the right side is brighter than the left.

3.3.3 Contour Segmentation

Contour segmentation is an interactive image processing method. Contours represent lines which join all the points through the boundary of an image with same intensity. Contours are used for analysing the shapes, detecting object and identifying the size of the object of interest.

After final image is extracted from preforming edge detection. Next, objects (contours) inside the image are identified; here purple colour is used to identify the objects. Also the area inside an object is coloured, but it consists of distinct hierarchy values. After this quadrate (rectangular) Region of Interest (ROI) is declared to determine the contours inside an image. When region of interest is declared, then one can choose to keep everything that overlaps with ROI otherwise trim the shape of the object with region of interest. Whole object of contour is filled with green colour when contour is identified in the ROI.

The isolated objects now can be part of plant structure. There can be many objects that constitute the part of plant structure sometimes, for example twisted leaves make the image appear as separate object. Thus, to effectively perform shape analysis of the plant image we need to combine object functions in order merge different plant objects into single object, then the outline of merged objects are coloured with blue in order to identify the complete shape of plant image. Divide plant object into a twenty equidistant bins and assign pseudo landmark points based upon their actual position. This data is scaled and this approach may provide some information about the shape independent of size of the image.

3.4 Feature Extraction

After completion of image segmentation process, all the useful features of plant are extracted. The next part is to perform the shape analysis of plant and identify the structure of the plant, height, width or area using the Boundary Line function. To determine coloured properties, coloured slice, pseudo coloured and colour analysed images are represented in histogram as shown in below figure 4.

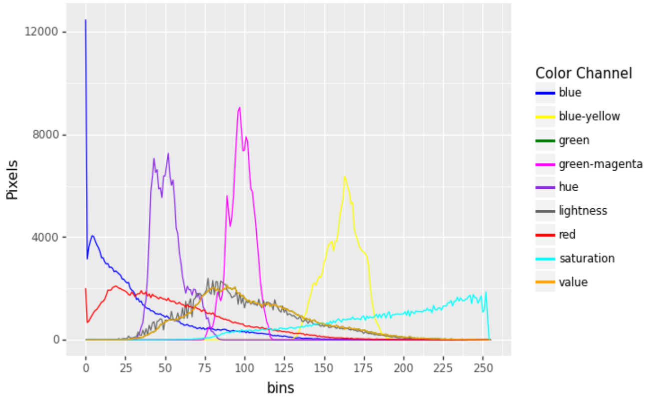

Figure 4. Colour histofram for different channels.

This histogram is used to represent the color values for each plant pixel [8]. The print_results function will take the measurements and stores the corresponding values whenever the below functions are executed, analyze_bound_horizontal, analyze_bound_vertical,analyze_color,analyze_nir_intensity, analyze_object, report_size_marker_area, analyze_area, analyze_width, analyze_height. Then output of print_results function is recorded in the JSON or CSV file format and segmented images are stored in the output folder. If no functions are exceuted, it will print an empty file.

IV. OBSERVATION RESULTS

The trials are carried out by using juypter notebook in python. Five plant images are taken for testing process. To test the accuracy and performance of different segmentation methods, the below three steps are used:

1) First, a pre-handled/pre-processed plant picture is taken as input.
2) Secondly, three segmentation methods namely Threshold segmenting, edge detection using Sobel Operator and Contour segmenting is used to obtain segmented plant image.
3) Third, the performance is evaluated based on different metrics namely Energy, entropy and UQI (Universal Quality Index).

Generally the estimation of Energy, Entropy and UQI should be greater that delivers high quality images, to demonstrate the efficiency of the proposed approach.

4.1 Energy

Using the below equation (3) the gray level energy is computed for different segmentation methods.

$$E(x) = \sum_{i=1}^{x} p(x) \quad (3)$$

The gray level energy with 256 bins is represented by $E(x)$ and probability distribution function is represented as$p(x)$, where it includes the histogram counts [9]. The minimum number of gray levels depends on higher energy value, which implies it is simple. The lower energy depends on large value of gray levels that implies it is complex.

The different energy values for distinct segmentation methods used are represented in Figure 5. By displaying high energy levels, it is proved as the proposed approach is efficient. A few example dataset images are shown in figure 6.

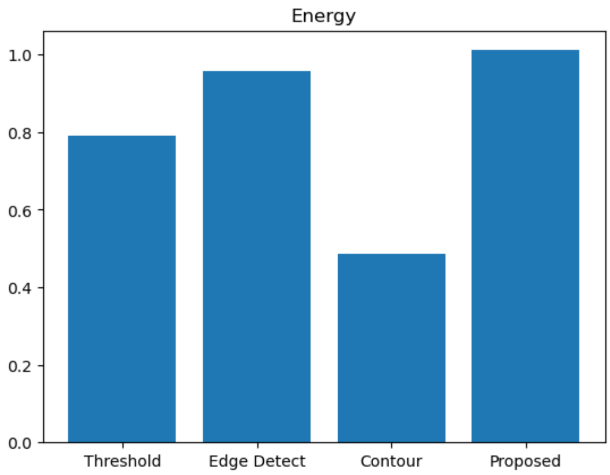

Figure 5. Energy levels for plant image.

Figure 6. Examples of plant image dataset.

4.2 UQI (Universal quality index)

The UQI estimates the values of distortion types across image similarity [9]. Computing UQI value is shown by equation (4),

$$\text{UQI} = \frac{4\sigma_{xy}xy}{[\sigma_x^2+\sigma_x^2][(\bar{x})^2+(\bar{y})^2]} \quad (4)$$

The UQI value graph for various segmentation methods is shown in Figure 7. It is proved that the proposed method is efficient by obtaining better UQI values compared to other methods as shown in Table 1. The UQI value ranges between [-1, 1].

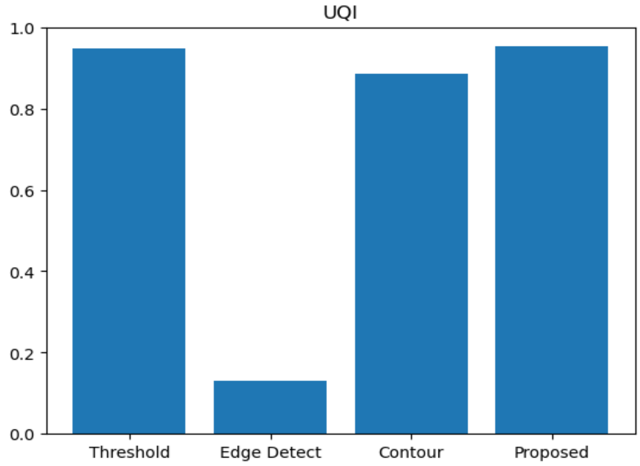

Figure 7. Plant image UQI values.

4.3 Entropy

The Entropy helps to determine the image texture or surface of the input image depending on the random statistical measure [10]. This measure evaluates the normal estimation of the data which present in an image, by taking two values of discrete likelihood distributions i.e. p and q and the calculation of entropy is shown in equation (5).

$$d = \sum_{i=1}^{k} p(i) \log_2 \frac{p(i)}{q(i)} \quad (5)$$

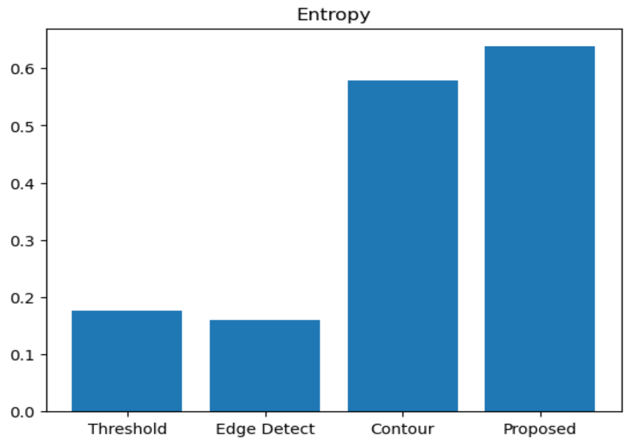

Figure 8. Plant image Entropy Levels.

The Figure 8 shows the graph of Entropy values for various segmentation algorithms. With higher entropy value it is proved that the proposed approach of combining various segmentation methods is more efficient compared to standalone methods used for segmentation.

Table: 1 Metric values for Different Segmentation Technique

Methodology	Energy	Entropy	UQI
Threshold segmentation	0.7923	0.1771	0.9476
Edge detection	0.9589	0.1591	0.1319
Contour segmentation	0.4866	0.5790	0.8856
Proposed approach	1.0114	0.6380	0.9527

Instead of using individual segmentation method, our proposed approach uses the combination of three different segmentation methods. The efficiency of proposed approach is validated by using Energy, Entropy and UQI metrics. The better values of these metrics prove that the proposed approach is the efficient method to perform plant image segmentation. High Energy value of the proposed method represents that the resulted image of proposed system contains very less noise and complete removal of background distortion in the image. Similarly, high UQI represents that segmented image is of high quality that is it is free from luminance and contrast distortion. Finally high entropy represents that the segmented image has clear surface area or texture that helps to perform effective shape analysis of the plant image.

V. CONCLUSION

This paper successfully explains the procedure to obtain better segmented images by combining different segmentation methods such as threshold segmentation, edge detection and contour segmentation. The threshold segmentation is used to remove complete background and noise in an image. Next, edge detection is used to detect boundary edges of an image without loosing any plant object or plant material. The contour segmentation is used to determine the structure of the plant in the image. After following the above segmentation methods on a raw plant image, the proposed work obtained well segmented plant image. After this features such as height, width and structure of the plant are extracted from the output segmented image. These important properties of a plant are automatically stored in the JSON or CSV file.

As said above the proposed approach is validated using Energy, Entropy and UQI metrics. We can conclude that the proposed approach is efficient and effective by observing better values for the above metrics as shown in Table 1. Thus, the observation results represent that the new proposed approach has improved quality of segmented image which in turn helps to improve the feature extraction of plant image.

ACKNOWLEDGMENT

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Dr. Ramakanth Kumar P is currently working as Professor and Head for the past two years. In the past, Professor served at various positions at RVCE. He served as HoD, ISE Department for 5 years and Dean Academics, RVCE for 4 years. His area of interest involves Natural Language Processing and Artificial Intelligence. He is actively involved in many research and consultancy work supported by many Government Agencies like DRDO, CABS, AICTE, NRB etc. and companies like Hewlett Packard, Nihon Communications, General Motors etc.

