A Smart Procedure for Severity Estimation of the Maize Leaf Diseases by the Use of Image Segmentation and Fuzzy Logic Inference

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Abstract: This paper explains a proposed taxonomic and smart procedure for severity estimation of the maize leaf diseases. However, few researchers have addressed the problem of disease severity estimation, but none have used a detailed procedure by the use of fuzzy logic. The present paper aims to broaden current knowledge of estimating the severity of plant leaf diseases by using fuzzy logic and image segmentation.

Keywords: image segmentation; northern corn leaf blight (Exserohilum); gray leaf spot (Cerospora); common rust (Puccinia sorghi); lab view

1. Introduction

Plant leaf diseases may pose a serious threat to Global food security if correct control measures are not seriously considered. The application of smart agricultural techniques such as machine learning models is progressively becoming an option for most of the commercial agricultural farmers. Plant leaf disease-detecting systems were modelled using different machine learning algorithms with outstanding accuracy results by researchers such as [1] [2] [3]. In the literature, most studies, of which the philosophy is the severity estimation of the plant leaf diseases, utilise laboratory based methods. Laboratory based methods are time consuming and require skilled plant pathologists. Direct methods of laboratory based plant leaf diseases were reviewed in the study by [4]. Few researchers such as [5] pioneered in the severity estimation of the plant leaf diseases by use of computer vision. In their study, they used image processing and fuzzy logic to estimate the severity of the plant leaf diseases. They used K-means clustering method to carry out segmentation of the diseased plant leaves. By means of fuzzy inference they were able to estimate the severities of the detected plant leaf diseases by grading them on a MATLAB based framework [5].

In computer vision, the recognition of objects, mostly depends on identifying particular shapes in an image. Clearly, using k means clustering for segmentation, however good it is, has a disadvantage of finding the k value by means of trial and error. In this study, we bring more knowledge on how to bear on the problem. Free hand selections were used in this study to select the region of interest (ROI) in an image, a solution that allowed us to set up general conditions to find an image diseased area that satisfied the conditions.

To refine the Free hand selections, the active contours were used. In an active contour framework, the refinement of free hand selected ROIs was achieved by evolving a closed contour to the diseased portion boundary, such that the contour tightly and entirely enclosed the diseased region. Figure 1 shows a diseased maize image that was marked in the region of interest (ROI) to be finely segmented by active contours as shown in figure 2.
The idea of using the active contours or snakes was to make fine segments by using the freehand selections of the regions of interest (ROIs), in order to get a curve level segmentation, not pixel segmentation that could be achieved by the use of other segmentation methods such as the graph cuts. Therefore, by using the active contours or snakes, the result is a segmentation curve that conforms to image edges. To determine the severity of the maize leaf diseases, a fuzzy logic inference system was used to grade the diseases according to the percentage of infections (POI).

This paper is organised as follows: In Section 2 we explain the Materials, Methodology and the Mathematical Principles of ideology. Our results are detailed and discussed in Section 3. Section 4 discusses the equations involved in the study as well as the results. Section 5 draws up a conclusion based on the objectives and the results of the study.

1.1 Related work

The idea of using k means segmentation of plant images to find the diseased leaf related areas was covered in the study by [5]. Fuzzy logic was used for decision making in terms of grading the plant leaf diseases, according to their severities [5]. The disadvantage of using k means in their study was that, [5] had to determine the value of k by trial and error. Also, they did not use any method for the refinement of the segmented image areas such as the active contours or snakes.

The segmentation of the diseased lesions on sugar cane by use rectangle and segmentation methods were proposed by [6] when they compared the segmented area to the leaf area. The purpose of their approach was to eliminate the usage of pesticides such that they were only applied according to the total calculated disease severity.
The method that was proposed by [7] utilised a Linear SVC classifier to classify the plant diseases according to levels. The levels were classified as Healthy class, Level 2 severity, level 3 severity and level 4 severity. What [7] did not explain in their study was how they graded the plant diseases according to their corresponding levels.

In this study, we carefully detail how freehand selections were applied to the regions of interest (ROIs) and refined by the active contours or snakes in order to calculate the area values of the ROIs. The percentage of infection (POI) of the leaf area was calculated by taking the ratio of the diseased leaf area ($D_{LA}$) to a total leaf area ($T_{LA}$). Fuzzy logic techniques were used to take the POI as an input to the fuzzy logic inference system for the estimation of the disease severities.

2. Materials and Methods

2.1 Materials

In order to analyse the images of the diseased maize leaves and estimation of their severities, we propose a method of selecting the diseased leaf regions of interest (ROI) by freehand, and finely segment them by use of the active contours or snakes. The ratio of the diseased leaf area ($D_{LA}$) to a total leaf area ($T_{LA}$) enabled the calculation of the percentage of infections (POI) which was utilised as the input to the fuzzy inference system for the estimation of the disease’s severity. Table 1 shows the materials that were used to perform the proposed procedure of estimating the severities of the maize leaf diseases.

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Contribution in the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiji ImageJ</td>
<td>Image processing package based on Java</td>
<td>Free hand selections and use of active contour segmentations</td>
</tr>
<tr>
<td>LabVIEW</td>
<td>Visual programming language from National Instruments</td>
<td>For modelling fuzzy logic inference system that estimated the severities of the maize leaf diseases</td>
</tr>
<tr>
<td>Maize field data</td>
<td>Maize dataset collected from the maize field by use of a smart camera and saved in Google drive</td>
<td>Tested for the disease severity estimations,</td>
</tr>
</tbody>
</table>
2.2 Methodology

Figure 3 shows the image processing steps that were followed in this study towards the culmination of the maize leaf disease severity estimations. To estimate the severities of the maize leaf diseases by means of fuzzy logic, we pre-processed the diseased images by use of Fiji ImageJ, an image processing package based on Java.

![Image Pre-processing Stages in Fiji ImageJ Processing Package](image)

Figure 3. Image pre-processing stages in Fiji ImageJ processing package for images.

It can be seen in Figure 3 that after the colour image acquisition, the acquired image was converted to Gray image of either 8-bit type, 16-bit type or 32-bit type. The next stage was to select all the diseased regions of interest (ROIs) by means of freehand selections available in the Fiji ImageJ package. To finely segment the selected regions of interest (ROIs) in the image, we utilised the active contours or snakes that are also available under the plugins in the Fiji ImageJ package. Finally, we calculated the percentage of infections (POI) and used it as input to the fuzzy inference system that was modelled in LabVIEW for the estimation of the maize leaf disease severities. The active contours or snakes can be further explained by considering their mathematical parameters as follows:

Finding the nearest detections: The detection of the contours perpendicular to the model is required to enter the cavities as well as the infolding. The snake makes its time steps as a list of \( p \) points \( N_1, \ldots, N_p \). Each of the \( N_i \) points is attracted towards the nearest edge, along the normal of that point. The Canny-Deriche operator is used for detecting the edges. From the initial position of \( N_i \), a search is made along the normal in search for the nearest pixel with a gradient magnitude, just above the specified threshold, within a specified distance range in both directions [8]. A candidate displacement \( \vec{D} \) will be the difference between this pixel and point \( N_i \). Without the consideration of regularization, the new position \( M_i \) of point \( N_i \) should verify:

\[
M_i = N_i + \vec{D}
\]  

(1)
The concept of regularization: The overall shape of the snake is kept as smooth as possible by minimizing the internal energy $E_{\text{int}}$:

$$E_{\text{int}} = \int (\alpha(s)|v'(s)|^2 + \beta(s)|v''(s)|^2)ds$$

(2)

$\alpha$ and $\beta$ are regularization parameters that vary along the curve, whereas $v(s)$ is the curve.

Discretization of (2) resulted in (3);

$$E_{\text{int}} = \sum_i \alpha_i |M_i - M_{i-1}|^2$$

(3)

By zeroing the partial derivatives of (3) yields to a linear system as follows;

$$(\alpha_i + \alpha_{i+1})M_i = \alpha_i M_{i-1} + \alpha_{i+1} M_{i+1}, \ i = 1 \ldots \ldots p$$

(4)

The minimisation of each point $M_i$ attraction towards the edges and regularization, results in the following system;

$$(\alpha_i^2 + 2\alpha_i \alpha_{i+1} + \alpha_{i+1}^2 + 1)M_i = (\alpha_i \alpha_{i+1} + \alpha_i^2)M_{i-1} + (\alpha_i \alpha_{i+1} + \alpha_{i+1}^2)M_{i+1} + N_i + \bar{D}_i$$

(5)

With $\alpha$ set to 0, the new point $M_i$ is simply $N_i + \bar{D}_i$. If $\alpha \to \infty$, the new point $M_i$ equals the barycentre points of $M_{i+1}$ and $M_{i-1}$. The parameters of $\alpha_i$ can be set in order to balance the smoothness between the curve and the closeness to the edges. To allow the model to enter the cavities, $\alpha$ can be computed as follows;

$$\alpha_i = \frac{\lambda}{1 + \mu \bar{D}_i}$$

(6)

where $\lambda$ and $\mu$ are coefficients for controlling the range of $\alpha$ values. $\bar{D}_i$ is seen as the norm of $\bar{D}_i$, normalised between 0 and 1.

2.3 Procedure

Step1: We acquired the images from the Web’s Google drive that were saved after they were collected from the maize field. The acquired images were then converted to a Gray image. Figure 4 shows the RGB colour image that was acquired while Figure 5 shows the acquired image after it was converted to a Gray image of 8-bit type.

Step2: Next, we selected the diseased portion on the Gray image as the region of interest (ROI) by use of freehand selections in the Fiji ImageJ package. We then segmented the region of interest (ROI) by use of the active contours that are available under the “plugins” menu of the package. The area of the segmented ROI was read under the “measurements”. The segmented area represented the diseased leaf area ($DL_\lambda$). Figure 6 shows the region of interest (ROI) in the diseased leaf image while Figure 7 shows the segmented ROI by means of active contours or snakes. Figure 8 shows the value of the segmented leaf area that was determined by use of the Fiji ImageJ. In case of multiple regions of interest, the average value of ($DL_\lambda$) was calculated (See equation9 for the calculation of POI in consideration of multiple ROIs). The calculation of the total leaf area ($TL_\lambda$) was calculated by using the rectangular selections in the package. This is shown in Figure 9 while Figure 10 shows the calculated total leaf area ($TL_\lambda$) in the Fiji ImageJ platform.
Figure 4. Acquired RGB colour image

Figure 5. Acquired image converted to Gray image of 8-bit type

Figure 6. A free hand selection of the ROI

Figure 7. A segmented ROI by use of active contours or snakes

Figure 8. $D_{L_4}$ results in pixels
Figure 9. Total leaf area ($T_{LA}$) marked by rectangular selections.

**Figure 10.** $TL_{A}$ results in pixels.

**Step 3:** We calculated the percentage of infections ($POI$) by using the diseased leaf ($DL_{A}$) and total leaf area ($TL_{A}$) as shown in (7).

$$POI = \frac{DL_{A}}{TL_{A}} \times 100$$ (7)

### 2.4 Model of Fuzzy logic inference system

Fuzzy logic is an elegant approach to vagueness and uncertainty that was proposed by Lofti Zadeh in 1965. It incorporates the use of heuristic linguistic rules to solve problems that cannot be modelled by conventional techniques [9]. The percentage of the infected leaf area was used as the fuzzified input to the fuzzy inference system proposed this study. The fuzzified output consisted of the diseased leaf severity scales. Table 2 summarizes the fuzzification of both the input and output for the fuzzy inference system proposed in this study.

<table>
<thead>
<tr>
<th>Input percentage of infections ($POI$)</th>
<th>Input $POI$ membership functions</th>
<th>Output scale of disease severity</th>
<th>Output membership grade of disease severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-20%</td>
<td>Low $POI$</td>
<td>1-10</td>
<td>Low severity</td>
</tr>
<tr>
<td>20-50%</td>
<td>Medium $POI$</td>
<td>10-20</td>
<td>Medium severity</td>
</tr>
<tr>
<td>50-100%</td>
<td>High $POI$</td>
<td>20-30</td>
<td>High severity</td>
</tr>
</tbody>
</table>
The proposed fuzzy logic inference system for the severity estimation of the maize leaf diseases, was modelled in LabVIEW. Figure 11 shows the input and output membership functions of the fuzzy logic inference system. The system was modelled with 3 fuzzy logic decision rules that associated the percentages of infection (POI) with their corresponding severity grades of the maize diseases. The degree of membership ($\mu$) determines how much of the input is involved with its membership function.

![Input membership functions for POI and output membership functions for the disease severity grades.](image)

The fuzzified control action of the inference system needed to be converted to a crisp output. The fuzzified output of the fuzzy logic inference system was converted to a crisp output by use of the equation (8) which is a defuzzifier formula. This defuzzifier uses the centre of gravity to compute the crisp output of the fuzzy logic inference system.

$$z_{COG} = \frac{\int \mu_c(z)z \, dz}{\int \mu_c(z) \, dz} \quad (8)$$
3. Results

Figures 12-17 show the 3-D surface results and fuzzy logic inference-system performance tests when rules 1 to 3 were invoked.

Figure 12. 3-D surface results when rule 1 was invoked.

Figure 13. Fuzzy logic inference test system to realize the feasibility of rule 1.
Figure 14. 3-D surface results when rule 2 was invoked.

Figure 15. Fuzzy logic inference test system to realize the feasibility of rule 2.
Figure 16. 3-D surface results when rule 3 was invoked.

Table 3 summarizes the fuzzy logic-system performance results for severity estimations of the maize diseases as shown in Figures 12-17.
Table 3. A summary of the fuzzy logic-system performance results for the severity estimation of the maize diseases as shown in Figures 12-17

<table>
<thead>
<tr>
<th>Input degree of membership</th>
<th>Input percentage of infections (POI)</th>
<th>Associated Input POI membership functions</th>
<th>Output scale of disease severity</th>
<th>Output membership grade of disease severity</th>
<th>Rules invoked</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99</td>
<td>10.529%</td>
<td>Low POI</td>
<td>5.49</td>
<td>Low severity</td>
<td>Rule 1</td>
</tr>
<tr>
<td>0.19</td>
<td>23.76%</td>
<td>Medium POI</td>
<td>15</td>
<td>Medium severity</td>
<td>Rule 2</td>
</tr>
<tr>
<td>0.99</td>
<td>75.11%</td>
<td>High POI</td>
<td>24.9</td>
<td>High severity</td>
<td>Rule 3</td>
</tr>
</tbody>
</table>

4. Discussion

The input percentage of infections (POI) for single ROI in an image was calculated by using equation (7). For multi regions of interest (ROIs) in the diseased images, we calculated the POI by means of equation (9) as follows;

\[ POI = \left( \frac{\sum DLA \text{ of multiple ROIs}}{\text{number of ROIs}} \right) \times 100 \]  

Equation (9) is simplified to;

\[ POI = \frac{\text{Average DLA}}{TLA} \times 100 \]  

The results show that the fuzzy logic decision rules were feasible.

5. Conclusions

The severities of the detected diseases were successfully estimated by the use of image processing and fuzzy logic decision rules. The method proposed in this study is accurate and yet time consuming. We suggest that future research be conducted on how the proposed method could be integrated in the form of an application as this would reduce the execution time of this method.

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References


