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Diagnosis of Tomato Leaf Diseases Using Fractal Dimension and Box Counting Method Based on Image Analysis

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Abstract

Diseases of tomato leaves, such as late blight, bacterial spot, and mosaic virus, pose a significant threat to agricultural production, necessitating early and accurate diagnosis. This study proposes a novel approach to diagnosing tomato leaf diseases based on fractal dimension analysis using the box-counting method. The method involves processing digital leaf images, binarization to highlight textural features, and calculating the fractal dimension, which reflects the complexity of the leaf structure. Experiments were conducted on a dataset of images comprising healthy leaves and leaves affected by various diseases to identify differences in fractal characteristics. The results demonstrate that the fractal dimension of healthy leaves significantly differs from that of diseased leaves and enables differentiation of disease types at early stages. The proposed approach shows potential for automating diagnostics in precision agriculture systems, offering high sensitivity and low implementation costs. Future research directions include integrating the method with machine learning technologies and developing mobile applications for real-time plant health monitoring.

Keywords: Box-counting, Solanum lycopersicum, Fractal dimension, Hausdorff Dimension.

Introduction

Tomatoes (Solanum lycopersicum) are a vital agricultural crop, but their yield is compromised by leaf diseases such as late blight, bacterial spot, and mosaic virus [1]. These pathologies cause substantial economic losses, necessitating early diagnosis to minimize damage. Traditional diagnostic methods, including visual inspection and laboratory analyses, are labor-intensive, subjective, or costly, limiting their applicability in large-scale production. Digital image processing offers promising avenues for automated diagnostics [2]. Fractal dimension, calculated using the box-counting method, enables quantitative assessment of textural changes in leaves

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caused by diseases [3]. This approach has proven effective in analyzing biological structures, yet its potential for diagnosing tomato diseases remains underexplored.
The objective of this study is to develop a method for diagnosing tomato leaf diseases based on fractal dimension analysis, compare the characteristics of healthy and diseased leaves, and evaluate the feasibility of early pathology detection [4]. The proposed method aims to provide an accessible tool for precision agriculture, with prospects for integration into plant monitoring systems.

II METHODS AND MATERIALS

The box-counting method is a versatile technique for calculating the fractal dimension of objects, regardless of their shape or strict self-similarity. It involves overlaying a grid of "boxes" (typically squares or cubes of uniform size) on the object [5]. The box size is progressively reduced, allowing analysis of how the number of boxes required to cover the object changes with scale (Figure 1).

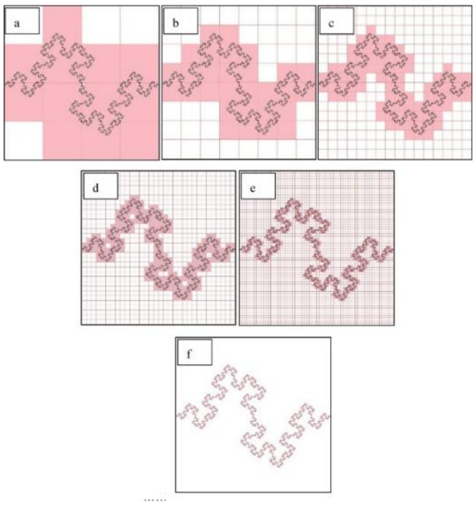

Figure 1. Overlaying a grid of boxes on the object

This method is particularly suitable for objects lacking strict self-similar structures, such as clouds, mountain reliefs, or tomato leaves.
The fractal dimension D is calculated using the formula:

$$D = \lim_{\epsilon \to 0} \frac{\log N(\epsilon)}{\log \frac{1}{\epsilon}} \tag{1}$$

where:

- $N(\epsilon)$ the minimum number of boxes of size required to cover the fractal;
- ϵ the side length of the box.

Here, $logN(\epsilon)$ represents the logarithm of the number of boxes, indicating how the box count increases as their size decreases, while, $log(\frac{1}{\epsilon})$ reflects the logarithm of the inverse box size, corresponding to the increasing scale. [6].

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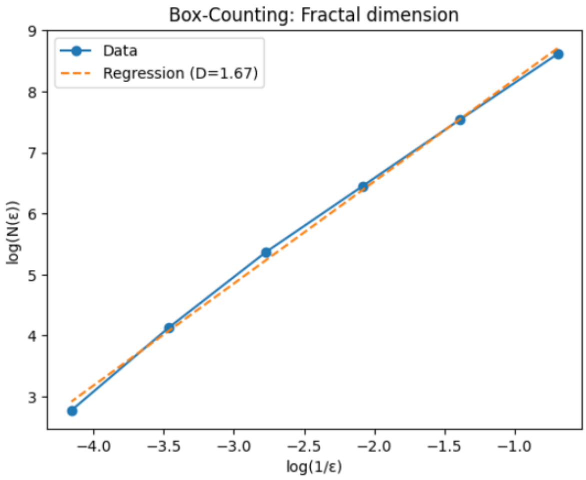


Figure 2. Box-counting

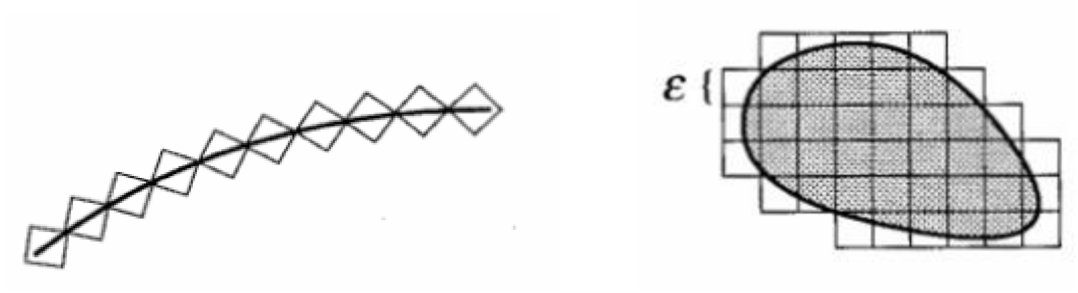
Informative features are key elements or properties containing critical information about an image's content, enabling recognition, classification, or analysis. In image recognition systems, these features are pivotal, as their identification allows algorithms to process images efficiently [7]. This approach is widely applied in fields such as medicine, agriculture, and remote sensing.

Typical informative features in images include:

- *Edges and boundaries:* Lines, contours, and object boundaries critical for recognition.
- *Corners and boundary points:* Specific points like corners, line intersections, or texture nodes serving as markers for object detection.
- *Color properties:* Color distribution aiding in object classification or attribute identification.
- *Texture properties:* Texture gradients or structural elements assisting in object selection and classification.
- *Shape and size:* Object shape, size, and proportions relevant for identification.
- *Object-specific features:* Unique attributes, such as facial landmarks or anatomical keypoints.

These are examples of features extractable from images for analysis and recognition. Combining multiple features with image processing and machine learning techniques enhances the accuracy and efficiency of recognition systems, particularly when using fractal dimension analysis to extract informative features.[8].

Fractal dimension is one way to determine the size of a set. In metric space it is called the fractal dimension of n- dimensional set and has several types. They are calculated as follows. Fractal (Hausdorff) dimensions are calculated using formula (1). Dimension is defined as the exponent *D* в $N(\varepsilon)\infty\frac{1}{\varepsilon^d}$ (Figure 2) [9].



a) Boundary block separation　　　　б) Total volume block separation

Figure 2. Hausdorff Dimension

a) Boundary block separation: $N(\varepsilon)\infty\frac{L}{\varepsilon}$,

b) Total volume block separation: $N(\varepsilon)\infty\frac{L}{\varepsilon^2}$,

Another example is the coastline method. The coastline length is measured in l, then the calculated length is calculated using formula (2) [10]:

$$L = \wedge\, l^{-\alpha}, \wedge = const \tag{7}$$

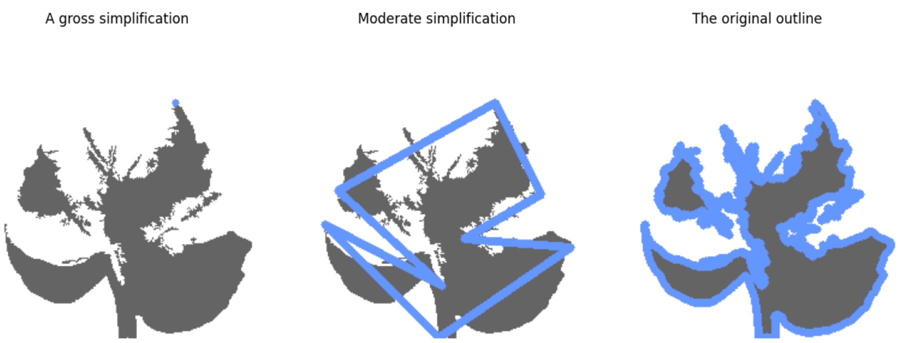


Figure 3. Total coastline length

Figure. 3, reflecting traditional concepts of geometry, shapes the scale according to predictable, understandable and familiar ideas about the space in which they are located. For example, take a line, divide it into three equal parts, and then each part will be 3 times less than the length of the original line. This also happens on the plain. If you measure the area of a square, and then measure the area of the square by $\frac{1}{3}$ the side length of the original square, it will be 9 times smaller than the area of the original square. This dimension can be determined mathematically using the measurement rule of formula (6):

$$N\,\infty\varepsilon^{-D}, \tag{8}$$

where, N is the number of parts, ε is the dimensional factor, D is the fractal dimension, ∞ means the proportion in this sign. This scaling rule confirms the traditional rules of scaling geometry, because for a line — $N = 3$, when $\varepsilon = \frac{1}{3}$, then $D = 1$, and for squares, because $N = 9$, когда $\varepsilon = \frac{1}{3}$, $D = 2$. The same rule applies to fractal geometry, but it is less intuitive. To calculate the unit

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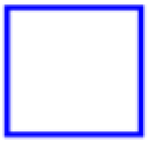
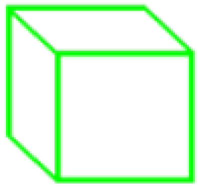
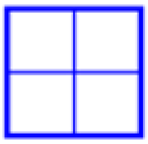
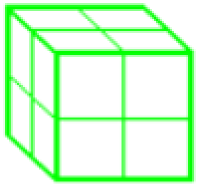
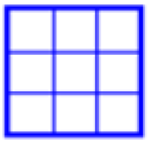
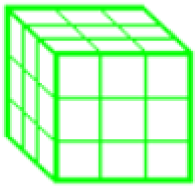
length of a fractal line, at first glance, reduce the scale by 3 times, in this case $N = 4$, when $\varepsilon = \frac{1}{3}$ and the value of formula (8) by changing formula (9) is derived [11, 12]:

$$\log_{\varepsilon} N = -D = \frac{\log N}{\log \varepsilon} \tag{9}$$

Table 1. Traditional representation of geometry in measurement and scale definition

	$D = 1$	$D = 2$	$D = 3$
$l = 1$	$N = 1$	 $N = 1$	 $N = 1$
$l = 2$	 $N = 2$	 $N = 4$	 $N = 8$
$l = 3$	 $N = 3$	 $N = 9$	 $N = 27$

III RESULT

The study analyzed images of tomato leaves for disease diagnosis using fractal dimension calculated by box-counting. Image processing and calculations were carried out in accordance with the described methodology, and the results are presented below.

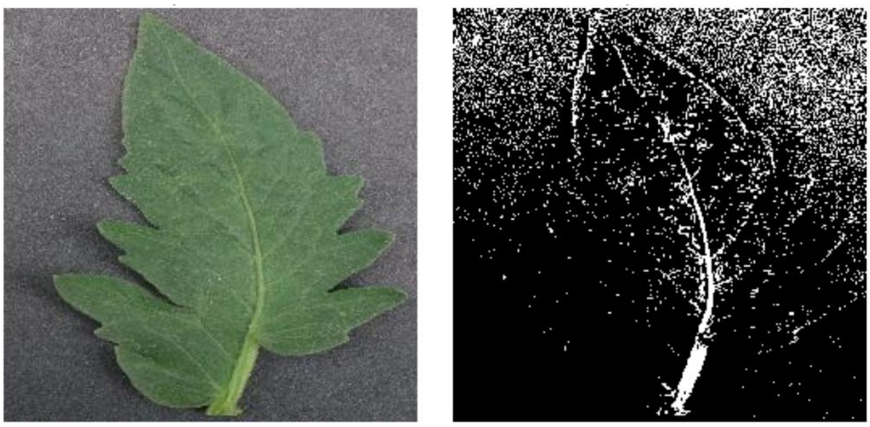


Figure 5. Binarization image

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Fractal dimension for different groups of leaves

Fractal dimension D was calculated for four groups: healthy leaves, leaves with late blight, leaves with bacterial blight, and leaves in early stages of disease. Mean D values and standard deviations for each group are shown in Table 2.

Table 2. Average values of fractal dimension for different groups of leaves.

Groups	Quantity of samples	Mean Fractal Dimension D	Standard Deviation
Healthy Leaves	50	1.82	0.05
Blight	50	1.65	0.07
Bacterial spot	50	1.58	0.06
Early stages of diseases	30	1.73	0.04

The results show that healthy leaves have the highest fractal dimension ($D = 1.82 \pm 0.05$), which reflects a more complex and homogeneous surface texture. Leaves affected by late blight ($D = 1.65 \pm 0.07$) and bacterial spot ($D = 1.58 \pm 0.06$) show a decrease in D, which is associated with the destruction of the leaf structure due to necrosis and spots. Leaves in the early stages of diseases have an intermediate value ($D = 1.73 \pm 0.04$), which indicates initial changes in texture that have not yet reached pronounced pathological manifestations.

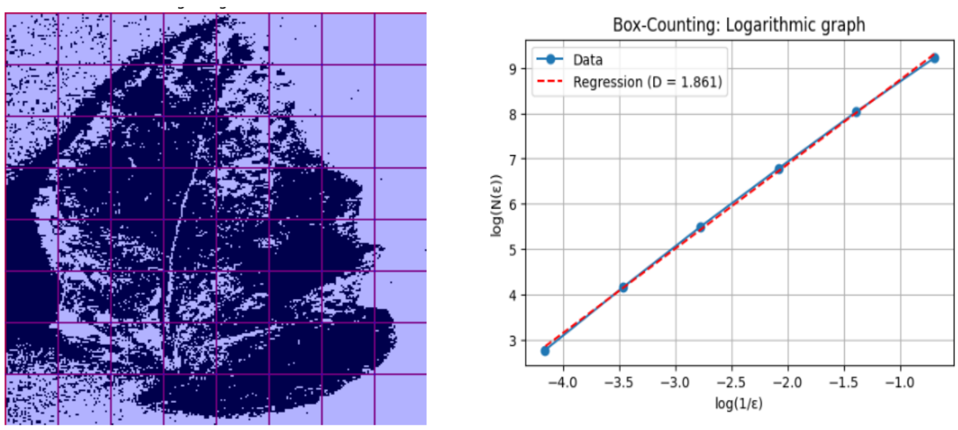

Figure 5. Box counting: Grid (sell sets = 32)

Figure 5 shows examples of binarized leaf images with a grid overlay for the box counting method cell size $\varepsilon = 32$ pixels. Healthy leaves exhibit denser cell coverage, consistent with their higher fractal dimension. Analysis of leaves in the early stages of diseases showed that the method is able to detect changes in texture $D = 1.73$ even before the appearance of pronounced visual symptoms. This confirms the potential of fractal analysis for early diagnosis, which is especially important for the timely application of agricultural measures.

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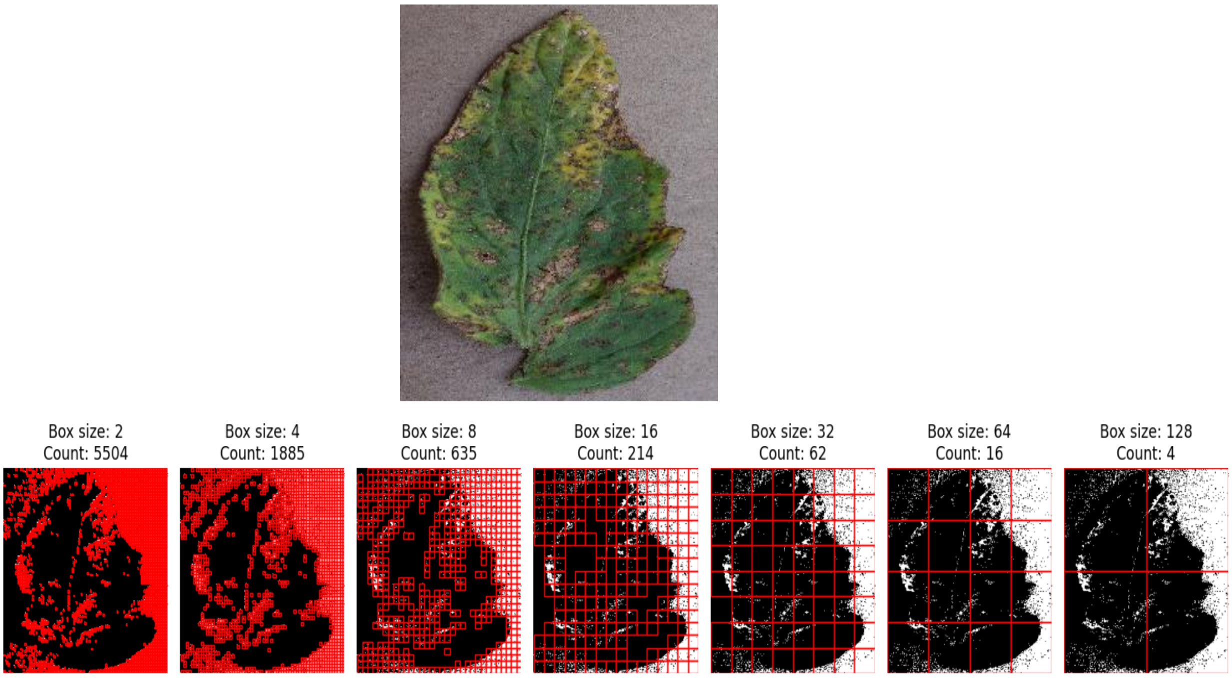

Figure 6. Box counting visualization

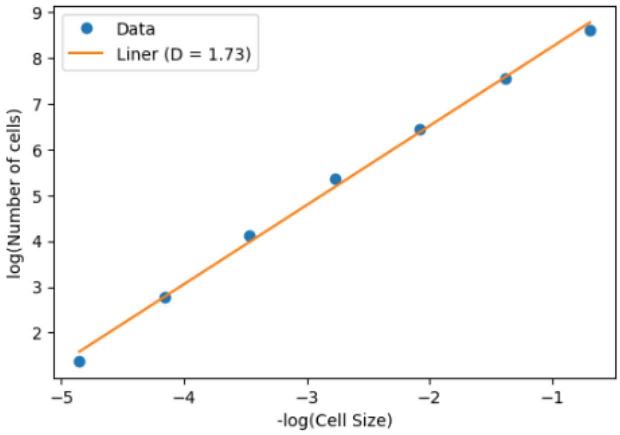

Figure 7. Regression chart

The concept of the coastline as a fractal object is applicable to the analysis of tomato leaves: the complexity of leaf contour and texture decreases with disease, which is reflected in a decrease in fractal dimension. This allows this approach to be used for diagnosing diseases, complementing the analysis of leaf texture with analysis of its edge. The method can be especially useful for the early detection of pathologies, when visual changes are still minimal.

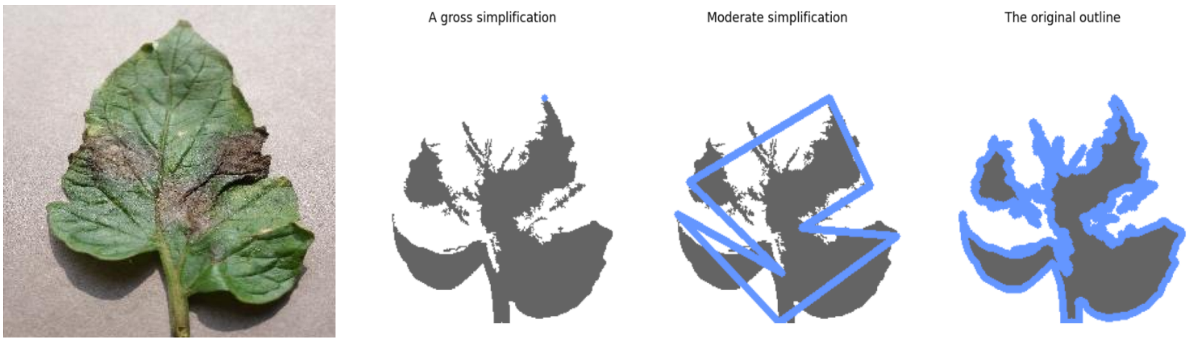

Figure 8. Leaf contours

The findings demonstrate that fractal dimension calculated by box counting is an effective indicator for diagnosing tomato leaf diseases. The method allows not only to distinguish between healthy and diseased leaves, but also to differentiate the types of diseases, as well as to identify pathologies in the early stages. These results confirm the applicability of fractal analysis in agricultural practice for automated monitoring of plant health.

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