Quantitative assessment of white spot (*Ramularia tulasnei*) disease severity of strawberry based on hyperspectral imaging

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Abstract. This study examined strawberry white spot disease severity using different hyperspectral imaging analyzing methods. The plant leaf images were classified by spectral angle mapper (SAM), by vegetation indices (RENDVI, GNDVI, MCARI) thresholds and by principal component analysis (PCA) method. The SAM method showed the overall accuracy 84% when classifying three types of visual symptoms of the disease.

1. Introduction

With a changing climate plant diseases cause significant economic losses in agriculture around the world. Early detection, quantification and identification of plant diseases are crucial for targeted application of plant protection measures in crop production. Traditional disease diagnostic methods, such as visual examination and microbiological laboratory analysis are expensive, time-consuming and labor-intensive. These shortcomings limit the application of these methods in large-scale farms.

Currently, new non-invasive techniques for plant diseases diagnostic using sensor technologies, robotics, computer vision and machine learning are rapidly developing [1]. New high-throughput methods are suitable for real-time applications and can provide the whole range of plant physiological parameters.

One such emerging sensor technology for non-destructive, rapid and automated plant diseases diagnostic is the hyperspectral imaging (HSI). Hyperspectral analysis extends the capabilities of traditional RGB image analysis by providing information beyond the visible spectrum.

Spectral profiles of healthy and diseased plants are different. The biotic and abiotic stress response can be indicated by the changes in tissue color, leaf shape, transpiration rate, canopy morphology, and plant density, and this process of biochemical changes is reflected in plant’s spectra [2]. Analysis of the reflection spectrum of plant tissue allows for the classification of healthy and diseased plants, assess the severity of the disease, differentiate the types of pathogens and identify the symptoms of biotic stresses at early stages, including during the incubation period, when the symptoms are not visible to the human eye [3].

Our aim was to explore the potential of hyperspectral imaging for the detection and identification of fungal diseases of strawberry. The objectives of our study were: (i) to compare the performances of five hyperspectral images classification methods; (ii) to assess the white spot disease severity of strawberry based on classification images.
2. Materials and methods
The remontant strawberry hybrid plants grown in greenhouse were used in the experiments. In July, 2021 we randomly selected 10 plants infected with Ramularia tulasnei and 4 health plants. Then leaves were detached from plants for further hyperspectral imaging. All infected leaves had visible symptoms of the disease: small, rounded, dark red or brown spots on the upper surface of the leaves with white spot’s center.

The hyperspectral reflectance measurements were performed with a line-scanning HSI system covering the visible and NIR wavelengths (475-900 nm with 3 nm spectral resolution, 2048x1088 px spatial resolution). It consists of a Photonfocus MV1 camera with IMEC CMV2K-LS150-VNIR sensor (Photonfocus AG, Switzerland), two linear halogen light sources, a moving platform and a computer.

Raw hyperspectral images were calibrated by white and dark references. Then three-dimension hypercube was acquired for each image. After that, the background of the corrected hyperspectral images was masked.

To differentiate healthy (green) and diseased (red and white) areas of leaves, the following classification methods were used.

Spectral angle mapper (SAM) [4]. This method is based on the assessment of the spectrum similarity of the studied object with the reference spectra. Three regions of interest (ROI) were defined for each strawberry leaf, corresponding to healthy leaf tissue, red spots and white spots. Then 50 pixels were selected randomly from each ROI. The resulting reference spectra were obtained by averaging 500 individual spectra.

Classification by the threshold value of vegetation indices [5]. For each hyperspectral image, a visualization map of the vegetation indices values was built. The belonging of a pixel to a certain class was determined depending on the range of index values. This article presents the results of classification by three indices: 

\[ \text{RENDVI} = \frac{(R_{750} - R_{705})}{(R_{750} + R_{705})}, \]
\[ \text{GNDVI} = \frac{(R_{750} - R_{550})}{(R_{750} + R_{550})}, \]
\[ \text{MCARI} = \frac{(R_{700} - R_{670}) - 0.2(R_{700} - R_{550})}{R_{700} / R_{670}}. \]

The principal component analysis (PCA) was used for classification [6]. The spectrum was linearly transformed into the space of the principal components. The classification was carried out according to the threshold value of the first component.

Results of classification were validated using confusion matrices.

All calculations were performed using the software ENVI v. 5.2 (ITT Visual Information Solutions).

3. Results
Spectral profiles of healthy and infected areas of strawberry leaves are shown in Figure 1. There are certain differences between the spectra of green, red and white areas. Thus, white areas have a higher reflectance intensity in the visible wavelength range (400-700 nm) and relatively low reflectance intensity in the near infrared range (700-900 nm) compared to other areas. Healthy areas have a characteristic peak at 550 nm, while red areas have a characteristic peak at 630 nm.
Figure 1. Spectral profiles of healthy and infected by Ramularia tulasnei areas of strawberry leaves

The difference in spectral characteristics was the reason for the use of the spectral angle mapper method (SAM), the principal component method (PCA), as well as methods of classification by vegetation indices (RENDVI, GNDVI, MCARI).

Table 1 contains the confusion matrices of these classification methods and their overall accuracy, defined as the ratio of the number of correctly classified objects in the ground truth data to the total number of objects. The SAM method yielded in the best overall accuracy over 84 %. The MCARI index threshold method had only 40% of overall accuracy.

| Classification result | Healthy (green) | Infected (red spots) | Infected (white spots) | Overall accuracy |
|-----------------------|-----------------|----------------------|------------------------|-----------------|
| **SAM**               |                 |                      |                        | 84%             |
| Not classified        | 0%              | 9.5%                 | 27%                    |                 |
| Healthy (green)       | 100%            | 10.5%                | 0.5%                   |                 |
| Infected (red spots)  | 0%              | 79%                  | 0%                     |                 |
| Infected (white spots)| 0%              | 1%                   | 72.5%                  |                 |
| **RENDVI**            |                 |                      |                        | 77%             |
| Healthy (green)       | 97.5%           | 46%                  | 0%                     |                 |
| Infected (red spots)  | 2.5%            | 46%                  | 13%                    |                 |
| Infected (white spots)| 0%              | 8%                   | 87%                    |                 |
GNDVI

|                | Healthy (green) | Infected (red spots) | Infected (white spots) |
|----------------|-----------------|----------------------|------------------------|
| Percentage     | 100%            | 0%                   | 0%                     |

MCARI

|                | Healthy (green) | Infected (red spots) | Infected (white spots) |
|----------------|-----------------|----------------------|------------------------|
| Percentage     | 99%             | 0%                   | 1%                     |

PCA

|                | Healthy (green) | Infected (red spots) | Infected (white spots) |
|----------------|-----------------|----------------------|------------------------|
| Percentage     | 100%            | 0%                   | 0%                     |

The different classification methods are visualized in fig. 2.

In order to assess the white spot disease severity of strawberry based on classification images, it is necessary to determine the percentage of the sum of the number of pixels in the two classes of infected areas to the total number of pixels in the image. For example, for the leaf in fig. 2, the classification by the spectral angle mapper determined 53,000 pixels out of 507,000 as infected, therefore, the degree of damage to this leaf was 10.5%.

Conclusions

Analysis of the reflectance spectrum using the spectral angle mapper method makes it possible to assess the white spot disease severity of strawberry leaves with an accuracy of 84%. At the next step of the research we are going to explore the potential of hyperspectral imaging technology for the early detection of fungal diseases of strawberries in the incubation stage.
Figure 2. Classification of white spot disease on strawberry leaf. The three classes ‘healthy’ (green), ‘red spots’ (red), and ‘white spots’ (blue) were separated using different methods: A1 – original image; B1 – SAM classification; A2 – RENDVI visualization; B2 – RENDVI classification; A3 – GNDVI visualization; B3 – GNDVI classification; A4 – MCARI visualization; B4 – MCARI classification; A5 – PCA visualization; B5 – PCA classification.
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