

Prototype of chili pathogen early detection system by using multispectral NIR/NUV

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Abstract. Chili plants (*Capsicum annum L.*) are a high-value horticultural commodity but are very susceptible to disease. Therefore, early detection of chili disease is essential to minimize the potential loss in chili farming. This research aims to develop a prototype for early detection of chili diseases before they become apparent to the human eye. In response to pathogens, chili plants produce substances that actively absorb and reflect ultraviolet light, while near-infrared images can reveal leaf cell structure damage. By considering these plant defense systems, the prototype system, developed with a closed growth chamber, focuses on capturing NIR and NUV images to detect plant diseases. It uses light reflectance in the near-ultraviolet and near-infrared spectrum as input for detecting diseases, coupled with image and pattern analysis for plants affected by viruses and fungi. The primary method of image analysis was texture analysis of NIR and NUV images, specifically image entropy analysis. The system was tested on plants with virus infection (Gemini virus), fungal infection (anthracnose), and under normal conditions. The results showed distinct differences in the image entropy values between virus-infected, fungal-infected, and non-infected leaves, especially from NUV images. This indicates that the system effectively utilizes NIR and NUV imaging to detect diseases, with texture and image entropy analysis serving as reliable metrics. Notably, the system is more effective at early detection of fungal infections (such as anthracnose) than virus infections (such as Gemini virus), with NUV imaging proving more effective than NIR for this purpose.

1. Introduction

Chili plants (*Capsicum annum L.*) are a high-value horticultural commodity but are very susceptible to diseases. Diseases that generally attack chili plants and fruit are damping off, fusarium wilt, bacterial wilt, anthracnose, Cercospora leaf spot, phytophthora blight, bacterial soft rot, yellow leaf curl, virus mosaic, and crackers. As it is used as the main spice in most Indonesian specialties, it holds significance in the Indonesian economy due to its multiplier impact. In the past few years, this commodity has disrupted the national economy of Indonesia due to diseases, climate change, and erratic weather.

One example of a chili plant disease is the yellow leaf curl disease. It is caused by the pepper yellow leaf curl virus which can develop over a long time, about 40-60 days after the plant is stabbed or infected by whiteflies. The process of developing the virus in the chili plants takes a long time depending on the health conditions of the plant. However, this can be accelerated if plant conditions are not healthy, for example, due to extreme climate change. If the plant is healthy, the yellow virus can also be hampered by its development. This infection can occur during breeding, so early detection at the time of transplanting can reduce losses significantly to the whole component of chili planting costs.



Theoretically, early detection of chili disease can be done before it is visible. This is made possible by referring to the photosynthesis process that is disturbed due to the presence of viruses or fungi in the body of the plant in the reflection or light reflectance of sunlight used by plant photosynthesis in the leaves used for detection, especially in the Near Infrared light spectrum (NIR) at 700 - 1000 nm and Near Ultraviolet (NUV) at (300 – 400 nm). The patterns in the spectrum bands are used for detection by using image processing and pattern analysis.

Nowadays, early detection of chili disease is undertaken based on knowledge-based symptoms that appear on these plants to decide the appropriate treatment for the prevention of the disease. Typically, this process relies on visible symptoms observed by humans. However, it is important to note that these symptoms also manifest in light spectra invisible to humans, and in general the interaction between pathogens and plants can be detected at an early stage [1]. Nevertheless, knowledge-based chili plant disease detection is currently still in plain observation, where there is only limited research for the development of knowledge based on multi-spectral (NUV and NIR). With this multi-spectral observation, it is expected that the prevention of plant diseases can be done earlier than if it only depends on visible observations.

Although not specific to chili, several studies have conducted multispectral analysis for the detection of pest and disease attacks [2] [3] [4] [5] [6] [7]. One example is tobacco leaf for TMV (Tobacco Mosaic Virus) attack with Visual, NUV, and NIR images. This is the basis for early detection of this disease using NUV and NIR images. A comprehensive review of the latest progress in the analysis of multi- and hyperspectral images was documented in [8]. It encapsulates diverse technological advancements, offers insights from researchers with varied scientific expertise, and emphasizes the significance of the research domain. It also highlights the crucial challenges that must be successfully addressed before these imaging techniques can be reliably applied in emerging real-world scenarios.

The objective of this research is to develop and evaluate a prototype system utilizing Near Infrared (NIR) and Near Ultraviolet (NUV) imaging techniques for the early detection of disease in chili plants. The research addresses significant gaps in the current methods of disease detection, which often rely on visual symptoms that appear only after the disease has progressed, making early intervention challenging. Specifically, the prototype aims to detect diseases at a much earlier stage, before they become apparent to the human eye. The prototype will undergo field testing using samples affected by both fungal and viral attacks to validate its effectiveness across different types of pathogens. This research also focuses on utilizing common PC specifications for early identification of chili diseases, bridging the gap between advanced imaging technology and accessible, user-friendly solutions for farmers. It is expected that the system will be further implemented on mobile devices (Android and other Mobile Technology) to enhance portability and ease of use in field conditions. This applied research provides an opportunity for chili farmers to detect disease attacks long before they are visible, enabling earlier prevention or treatment measures and thereby reducing potential losses in their agricultural fields.

2. Material and Method

This research utilized chili plant samples, including healthy plants, those infected with a fungus (anthracnose), and those infected with a virus (yellow leaf virus). The primary equipment employed consisted of four small growth chambers, a camera, an NIR/NUV filter, and a PC with 16 gigabytes of memory. The software employed included Webcam 7 for capturing images from eight cameras at specific intervals and storing them on the hard drive with designated filenames, the Matlab Image Processing Module for image analysis, and MS Visual Basic for processing high-resolution images. A PC with relatively large memory, at least 16 GB of memory, was required for image processing due to the large image and number of images involved. MS VB is needed considering that Webcam 7 is only capable of standard image resolution where for certain cases the maximum camera capability (5 Megapixel) needs to be used for detailed images. The research was carried out in three stages, i. e. proof of concept, prototyping, and testing.

2.1. Proof of Concept.

Initial research on leaf image preprocessing has been carried out [9], which introduced a straightforward image-processing method related to light reflectance in photosynthesis shown in Figure 1. The method aims to identify the leaf area in images (Leaf Area Identification) and stands in contrast to conventional techniques that primarily emphasize the visible spectrum, requiring a complex combination of image processing methods and substantial computational power. This method focuses on the leaf's light absorption characteristics in the NUV and NIR spectra. Experimental validation was carried out using NUV and NIR optical filters for cameras to demonstrate the feasibility of the proposed concept. This involved modifying the camera by substituting the existing filter with the one necessary for the initial testing of samples from plants that had experienced attacks.

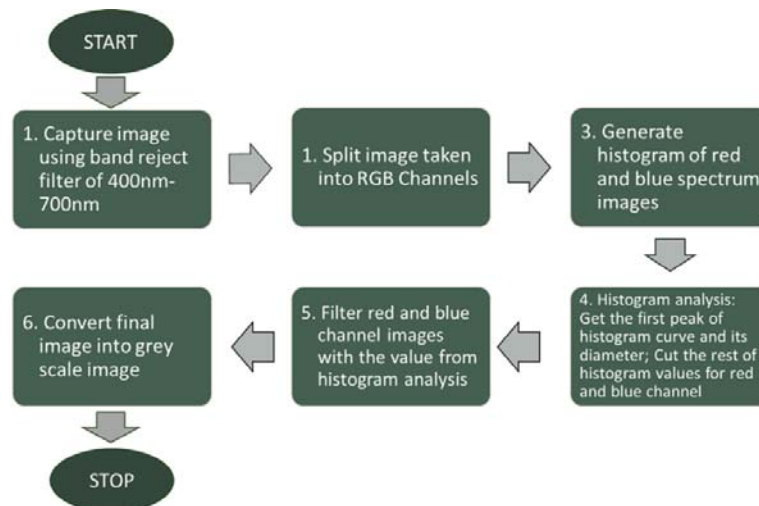


Figure 1. Leaf image processing method

The proof of concept is divided into two parts, namely seedling and planting of chili in small growth chambers. In this stage, non-infected chili seeds were selected and seedling was carried out inside isolated spaces (small growth chambers), aiming to minimize the impact of infections from other diseases. The Blotter test technique is employed to assess the seed health concerning latent pathogens within the seeds. Seedling was carried out without using soil but with rock wool, husks, and sterile cocopeat media. This was intended to reduce the possibility of latent pathogens in the soil media. Two treatments for test samples were undertaken, i. e. fungal infection on chili seeds and viral infection on chili seeds. Image Capture (NUV and NIR) for the above samples was undertaken at regular intervals, followed by verification of the final samples through laboratory tests for the respective cases using a digital microscope with NUV and NIR illumination. Multi-spectral chili knowledge-based image data was processed and stored for future development using Webcam 7, MS Visual Basic, and Matlab software to observe early attack patterns in the NUV and NIR spectra.

Arising from the initial suspicion that there are differences in the patterns between healthy and diseased leaves, a logical choice for image processing is texture analysis. There are many texture analysis parameters, one of which is quite common is entropy. It is a randomness statistical measurement of a pixel in a grayscale image that can be used to characterize the texture of an image [10]. A maximum entropy threshold method combined with a genetic algorithm has been used for image segmentation of maize leaf disease [11]. Entropy has also been used for extracting image features in cucumber leaf disease recognition [12]. Before processing the entropy analysis, the leaf image is cropped so that it only shows the leaf portion by removing the background image. The entropy is calculated by using equation (1). MATLAB Image Processing Toolbox is used for this purpose.

$$H = - \sum_{k=0}^{M-1} p_k \log_2(p_k) \quad (1)$$

where M is the gray level and p_k is the probability associated with gray level k . Maximum entropy is achieved when a uniform probability distribution occurs while minimum entropy is achieved when the image is constant with almost all pixels having the same gray level.

2.2. Prototyping.

In this phase, tools for both hardware and software are produced and assembled. The prototype offers advantages in revealing imperceptible symptoms within the human visual spectrum (400 – 700 nm). The approach entails identifying image analysis features suitable for classification, enabling the observation of initial attack patterns in the NUV and NIR spectra.

2.3. Testing of the set of plant samples on the prototype

At this stage, experiments were carried out with instrumentation that was developed with three cases, namely observation of healthy leaves, the transmission of Gemini virus, and the transmission of anthracnose fungus. In epidemiology, the typical duration for observing plant and disease interactions is 21 days. However, aligning with the goal of early disease detection, the observation period was shortened to 9 days, specifically on days 1, 3, 7, and 9 after planting.

3. Results and Discussion

3.1. Proof of Concept

For proof of concept, the feasibility test of the digital camera and the Hoya U-330 as Near UV Bandpass and Near IR Bandpass optical filters with spectrum characteristics as Figure 2 was undertaken.

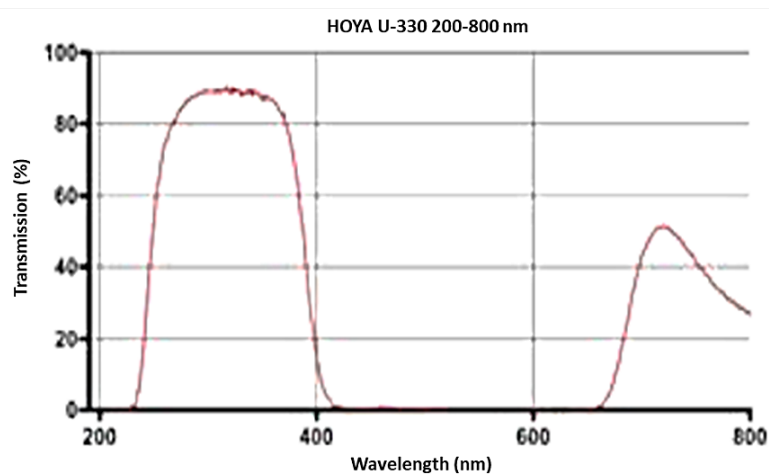


Figure 2. Spectrum characteristics of the Hoya U-330 optical filter

As examined by [13] and [14], digital cameras are generally able to capture NUV and NIR and, therefore can be used for multispectral sensors where CMOS and CCD cameras are proven capable of capturing NIR and NUV light. Figure 3 shows a comparison between the catching spectral sensitivity of the human eye, CMOS, and CCD [15].

Initial trials were carried out on chili plants that had been fruiting with an instrument developed, in which there were two cases, the first (case 1) was chili plants with most of the leaves having symptoms of the disease as shown in Figure 4, and the second (case 2) were similar chili plants that still look healthy (Figure 5).

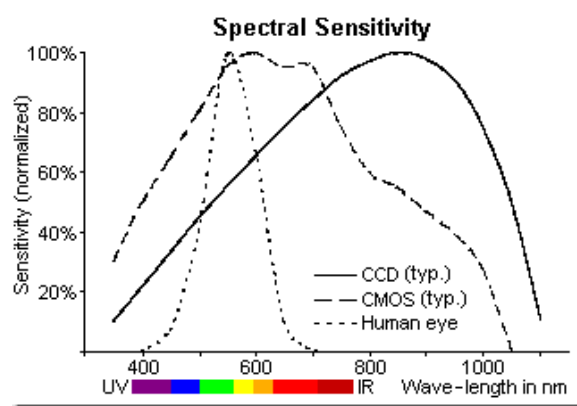


Figure 3. Spectral sensitivity: comparison of the human eye, CCD, and CMOS sensors [15]



Figure 4. Sample of an adult chili plant that has a disease



Figure 5. Sample of healthy leaves for NUV/NIR observation




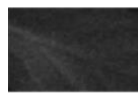










For this experiment, a 150-watt Halogen lamp was used as a lighting source to compare it to the same light source. The results of NUV and NIR image texture analysis obtained from case 1 and case 2 are summarized in Table 1.

From Table 1 it can be discerned that the average NUV entropy for case 1 (chili plants with disease) is 5.8952 and for case 2 (healthy chili plant) is 5.0479. Meanwhile, the average NIR entropy for case 1 is 5.1766 and for case 2 is 4.8736. Figure 6 shows a comparative visualization of the two cases using a box plot which shows that there is a significant difference between the two cases, especially in the NUV entropy. Thus, the trial test of the instrument shows the potential use of entropy of Near UV images for the detection of plant disease. The differences in the sensitivity of NIR and NUV imaging to water content and physical characteristics explain why NIR entropy does not show significant differences between healthy and diseased plants, while NUV entropy does.

With reference to plant defense [16], plants will release signaling agents that trigger plant defense systems, such as cell thickening. What is intriguing about this exposure is that the signaling agent absorbs NUV light during the process. Although further tests are needed, this characteristic of NUV absorption suggests that there could be variations in how ultraviolet light is absorbed by the leaves. This

potential variation could help in distinguishing different types of plant responses or conditions. In contrast, no specific pattern was observed in the entropy of NIR images during this experiment. This lack of pattern is likely related to the nature of NIR rays, whose reflection is influenced by the extent of damage to plant cells, particularly leaf cells.

Table 1. Proof of concept on healthy and diseased chili plants

Case 1 (chili plants with disease)			Case 2 (healthy chili plant)		
UV Image Cut	Entropy NUV	Entropy NIR	UV Image Cut	Entropy NUV	Entropy NIR
	6.1758	5.2415		5.1867	5.0585
	4.9683	4.7479		4.8606	4.8195
	5.9705	5.3101		5.8644	5.5859
	6.5475	5.4409		5.0829	4.7979
	5.7893	4.8556		4.8427	4.8794
	5.7154	4.6676		4.4947	4.2291
	6.0997	5.9726		5.0032	4.7449
Average	5.8952	5.0479		5.1766	4.8736

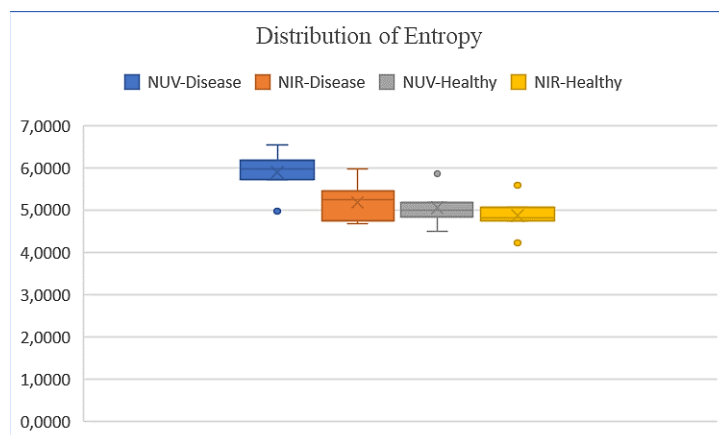


Figure 6. Distribution of NUV and NIR entropy in case 1 and case 2

3.2. Prototyping

The prototype is intended for an initial trial during the chili nursery to test the camera with NUV optical bandpass and NIR bandpass filters. Then it was used for initial experiments as part of the Proof of Concept for the observation of NUV and NIR of chili leaves as well as for testing its capability to early detect disease attacks.

Figure 7 demonstrates the PC configuration and 4 small growth chambers for early detection of chili diseases.

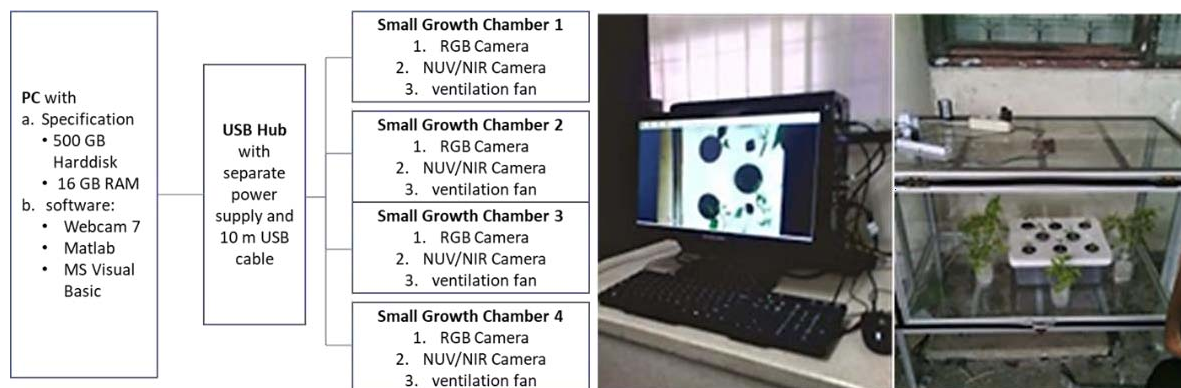


Figure 7. Prototype of Chili Pathogens Early Detection System in the form of a PC configuration and 4 Small Growth Chambers

3.3. Testing with virus and fungal transmission on the prototype

As the control, plants for observation of healthy leaves were relatively young, having an average of 8 leaves. In the small growth chamber, 8 plants were placed. Of the 8 plants, 3 plants with wide enough leaves were taken randomly and 3 pictures of leaves were taken from each plant.

To observe the transmission of the Gemini virus, the virus was intentionally transmitted to all parts of the experimental plant at planting time with the help of a whitefly vector. There were 8 plants in one small growth chamber, 10 whiteflies were required for each plant. On the 7th day of observation, one plant showed visible wrinkling of the leaves.

For fungal diseases, transmission is relatively easy, namely by spraying healthy plants with a liquid obtained from soaking chilis infected with anthracnose. Before spraying, the soaked chilis were crushed and filtered. This is in contrast to virus transmission which depends on vector movement, the evenness of spraying may be related to the rapid change in NUV entropy (with relatively the same NIR entropy) on the third day after transmission. Another difference is that during virus transmission the leaf area decreases (wrinkled), whereas during fungal transmission there were no visible physical changes to the leaves. The summary of all observation results, in terms of average image entropy in each observation time, is exhibited in Figure 8. Table 2 provides information on the range of observation results.

From cases of (1) normal/healthy leaves, (2) leaves infected with Gemini virus, and (3) leaves infected with anthracnose fungus, it was observed that the delta (the difference between the maximum and minimum) of NUV entropy and delta of NIR entropy for cases (2) and (3) were relatively higher compared to those from healthy plants. However, for virus transmission, the average NUV entropy (days 1, 3, 7, and 9) was relatively unchanged, and there were fluctuations in the average NIR entropy. Experiments at this stage cannot confirm whether this is related to leaf wrinkling or due to the absence of the Gemini virus. Further research is needed to confirm this issue. The average NIR entropy for fungal transmission was slightly changed from day 1 to 9. However, there was a significant increase in the NUV entropy average. These results indicated that NUV and NIR perform better in the early detection of fungal transmission compared to virus transmission. This is likely due to the more pronounced structural changes and visible symptoms caused by fungal infections, which are more detectable through these imaging techniques.

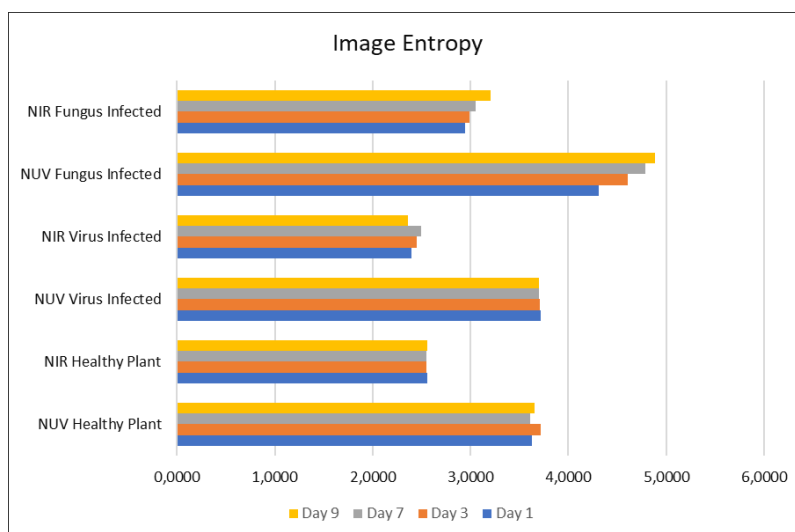


Figure 8. Average image entropy in each observation time

Table 2. Range of observation results in trials with virus and fungal transmission

Observation	Healthy Plants	Plants infected with the virus	Plants infected with fungus
Delta (Maximum – Minimum) NUV Entropy	0,2928	0,5796	0,8451
Delta (Maximum – Minimum) NIR Entropy	0,1090	0,3515	1,0151

3.4. Potential use and further development

The developed prototype can be applied especially to chili seed companies or chili farmers in general, especially when transplanting from nurseries. The nature of latent viruses and fungi in chili seeds for sale can be reduced by better monitoring of this tool where this can be detected when transplanting from breeding so that it can reduce farmers' losses significantly. This will provide early benefits for detecting chili diseases so that farmers' losses can be reduced as early as possible and increase planting success.

Further possible development is directed towards portable/mobile devices for the early detection of diseases in plants that enable use in the field. One possibility is for applications on smartphones or tablets as a continuation of this applied research. In this case, the challenges of using cameras in the field need to be taken into account carefully. The image of the object may be backlit (dark). Apart from that, another challenge that may be encountered is the appearance of shadows. The view is disturbed by the glare of the sun and over-lighting, so the image is not as natural as expected. These may need some additional steps in the image processing. Future development should focus on improving image analysis techniques, potentially incorporating advanced machine learning methods, and expanding the spectral range used for detection. Integrating the detection system with IoT technologies for real-time monitoring and applying these techniques to other horticultural crops could also be valuable avenues for future research.

4. Conclusion

Proof of concept tools and the prototype for early detection of chili pathogen/disease have been developed by taking NUV and NIR images for image entropy analysis. By using those devices, it can be concluded that NUV and NIR images of leaves can be used as input for detecting a pathogen/disease attack on chili plants. The key findings indicate that the system effectively utilizes NIR and NUV

imaging to detect signs of disease, with texture analysis and image entropy analysis serving as reliable metrics. NUV and NIR images can be used for early detection of anthracnose fungus-infected plants, demonstrating higher efficacy in detecting fungal infections compared to virus infections. This higher efficacy is likely due to the more pronounced structural changes and visible symptoms caused by fungal infections, which are more detectable through these imaging techniques.

However, the system's performance for early detection of Gemini virus-infected plants is not yet confirmed. Further research is needed to enhance the detection capabilities for viral infections. Future development should focus on improving image analysis techniques, potentially incorporating advanced machine learning methods, and expanding the spectral range used for detection. Additionally, efforts should be made to field test the prototype under diverse environmental conditions and to develop portable, user-friendly versions of the system for practical use by farmers.

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