

Development and Simulation of a Hue-Based HMI Application for Vegetable Leaf Greenness Analysis

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Abstract—This study aims to design, develop, and evaluate, through simulation, a Visual Basic 6.0-based HMI (Human-Machine Interface) application to support the analysis of leaf greenness using the Hue feature in the HSV (Hue, Saturation, Value) color space. The system consists of a camera, a Wi-Fi modem/router, a PC, and the HMI application. This application was developed to load or capture images, read RGB values, convert RGB to HSV, calculate Hue and Saturation, and visually classify leaf green colors. The novelty of this research lies in the integration of a simple workflow—comprising image acquisition, color conversion, Hue extraction, rule-based classification, and simulation testing—within a single HMI interface. Evaluation was conducted through black-box testing, algorithmic verification of RGB-HSV conversion, and sRGB/CSS color fixtures. The results show that all application functions operate as designed and that the generated Hue values are consistent with the reference formula. This research is the result of a software prototype that can be applied to the conversion from RGB to HSV, which has been validated within a Human-Machine Interface (HMI)—not merely for the physiological validation of plants, nor for its quantitative advantages over other color indices, but as a foundation for students to develop image-based leaf analysis in future research.

Keywords—HMI; visual basic 6.0; Hue; HSV; RGB; leaf green; simulation; black-box testing; image processing

I. INTRODUCTION

Leaf green color is a visual characteristic often used to quickly assess plant condition [1][2]. Image-based chlorophyll measurement is non-destructive and requires no special equipment other than a digital camera [3][4]. In leafy vegetables, a color change from green to pale green or yellowish is often associated with changes in leaf pigments, symptoms of chlorosis, or differences in nutritional status. However, visual observation of leaf color has limitations because it is subjective and influenced by the observer's perception, lighting, viewing angle, and camera settings.

Advances in digital image processing allow leaf color to be analyzed more objectively through pixel values [5]. Camera images are generally in the RGB color space, which is a combination of red, green, and blue channels. To analyze changes in color direction, RGB can be converted to the HSV

color space, which separates color into Hue, Saturation, and Value. Hue indicates the dominant color type, Saturation indicates the purity of the color, while Value indicates the level of brightness. With this separation, Hue can be used as a computational parameter to distinguish between green, pale green, and greenish-yellow.

Several previous studies have used digital images to estimate chlorophyll, nitrogen, or plant nutrient indices [6]. However, most of these studies involved real plant data, physiological measurements, and relatively complex predictive models. A limitation of this research is the lack of chlorophyll meters, SPAD data, leaf nitrogen data, and real leaf images collected under controlled conditions. Therefore, this study focuses on the design of an application program and simulation-based evaluation, rather than on physiological validation of plants.

The contributions of this study are: 1) designing a Visual Basic 6.0-based HMI application to support leaf greenness analysis; 2) implementing modules for RGB extraction, RGB-to-HSV conversion, and the calculation of Hue, Saturation, and Value; 3) developing a simulated test scenario based on RGB color samples; and 4) evaluating the application through black-box functional testing and computational verification. Thus, this study is positioned as a study on the design and development of software to support leaf color analysis, rather than as an agronomic study that concludes actual plant health. This research contributes to the development of a prototype framework that can combine RGB and HSV techniques within a Human-Machine Interface (HMI), in addition to a new color classification algorithm that claims to outperform existing indices such as ExG, NGRDI, or the G/R ratio.

The innovation of this research lies in the development of a software artifact that integrates the structured analysis of leaf greenness into a single HMI. The developed application combines functions for image loading or acquisition, RGB extraction, RGB-to-HSV conversion, hue and saturation calculations, rule-based color classification, and result storage. Thus, the main contribution of this research is a prototype application supporting visual leaf analysis, rather than an agronomic prediction model.

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The novelty of this research can be explained in four aspects: 1) this research positions Hue as a computational feature implemented directly within the HMI application, allowing users to obtain Hue values without additional image processing software; 2) this study provides a simulated evaluation scenario that can be replicated using an sRGB color fixture, allowing the RGB-HSV logic and classification rules to be verified before being applied to real leaf images; 3) This study establishes a classification rule, in which the average value ($V > 0.55$, $0.40 \leq V \leq 0.55$, or $V < 0.40$) is used within the green hue range (105° – 160°), to distinguish between normal green, dark green, and very dark green, thereby defining the role of the Value in this classification comprehensively and in detail; 4) This study combines black-box functional testing and algorithmic verification, ensuring that the evaluation demonstrates not only the application's visual output but also the consistency of the computational process.

Compared to previous studies that focused on predicting nitrogen levels, SPAD values, chlorophyll content, or plant classification using machine learning, this study focuses on the early stages of software engineering. Therefore, the contribution of this study is to provide a simple, ready-to-develop HMI platform for further validation using real leaf images, SPAD measurements, chlorophyll measurements, nitrogen measurements, or machine learning models.

Several previous studies on Vegetable Leaf Greenness Analysis have been conducted by the following researchers: Research on leaf cutting and precision rooting from the perspective of automation has been completed and analyzed in study [21]; furthermore, research on fabrication and performance analysis—specifically regarding pineapples—has also been comprehensively addressed in study [22]. Study [23] provides a detailed analysis of green tea seed and leaf extracts against HCl and ethanol, while study [24] provides a detailed and comprehensive analysis of green TiO₂ nanoparticles derived from *Corchorus olitorius* leaf extract for the solar and UV photocatalytic degradation of methylene blue and tetracycline, whereas study [25] discusses in detail and specifically how green zinc oxide nanoparticles from *Tagetes erecta* (L.) leaves reduce *Meloidogyne incognita*-induced stress in *Solanum lycopersicum* (L.).

II. STUDY LITERATURE

A. The Position of This Study in Relation to the Literature

Digital image-based leaf color analysis has been widely used in precision agriculture, including the use of digital cameras to estimate chlorophyll content and nitrogen concentration [7] [8]. Various modern imaging techniques for plant nutrient analysis have also been widely employed [4], while other studies have shown that RGB-image-based indices for romaine lettuce correlate with nitrogen and chlorophyll status [9]. These studies indicate that leaf color can serve as a relevant visual feature for crop monitoring.

A study on pak choi used digital imagery and machine learning to estimate the Nitrogen Nutrition Index [10]. Other studies utilized the RGB, HSV, and L*a*b* color spaces to extract leaf color features [11] [12]. However, the focus of those studies was on physiological or agronomic predictions. In

contrast to these approaches, this study developed an HMI application that processes color through simulation and uses only visual categories as its initial output.

For software development purposes, standard color references are required so that simulation scenarios can be replicated. The MDN Web Docs documentation provides a list of CSS named colors in the sRGB color space with clear HEX/RGB values [13] [14]. These values can be used as a technical reference for creating simulated color samples, not as physiological plant data. Additionally, OpenCV explains that HSV is often used for color separation because Hue represents the type of color, although the Hue scale may vary between software programs [15].

Software testing is conducted using the black-box method because the application is evaluated based on the correspondence between input and output, not on the internal structure of the program code. Software testing literature explains that black-box testing is suitable for evaluating functions based on specifications and usage scenarios [16]. Thus, this method is appropriate for evaluating HMI functions such as image loading, selection of the analysis area, RGB extraction, HSV conversion, hue calculation, classification, and result storage.

The literature on leaf color analysis indicates that RGB and HSV images, green-channel-based indices, and color parameters such as the hue angle have been used to estimate chlorophyll, nitrogen, or the greenness of plants [17], [18]. Some studies use physiological measurements as a reference, such as SPAD, chlorophyll concentration, leaf nitrogen, or the Nitrogen Nutrition Index [19]. This group of studies is important as a theoretical basis for the idea that changes in leaf color from green to yellow are related to changes in pigments and nutritional status, but their approach requires actual plant data and supporting measurement tools.

Another group of researchers has developed image processing and machine learning systems for plant phenotyping, disease diagnosis, or the estimation of physiological traits [17]. These approaches offer high performance but often require real-world image datasets, annotations, model training, and field validation. In contrast to these approaches, this study is limited to the design of an HMI application and simulated testing; thus, its primary output is a preliminary software prototype that verifies the RGB-HSV-Hue computational workflow.

The software testing literature supports the use of black-box testing to assess functional correctness based on input and output without examining the internal structure of the code [16]. In this study, black-box testing was used to ensure that the application modules functioned as designed, while algorithmic verification was used to ensure that the RGB-HSV-Hue calculations were consistent with the reference formulas. The OpenCV and MDN Web Docs documentation were used as technical references for the HSV color space and the sRGB/CSS color standards [13].

In addition, study [26] discusses “Spinach Leaf Biomass Valorization through Coenzyme Q10 Recovery and Its Application in the Green Synthesis of Silver Nanoparticles”; the results of this analysis provide a detailed and comprehensive physicochemical characterization and assessment of antioxidant

activity, while study [27] discusses “Green Extraction of RuBisCO-Rich Leaf Protein for Sustainable Food Systems”; the results of this study identified an efficient, high-quality, and sustainable process. Meanwhile, study [28] investigated cassava root-leaf mixtures using a Box-Behnken design; study [29] conducted an investigation and optimization of patchouli leaf waste extract (PLWE) as a green corrosion inhibitor for aluminum in HCl via a Box-Behnken design; and study [30] focused on the green fabrication of ZnO@ZnS binary nanocomposite using Butea monosperma leaf extract.

B. Hue Assumption Data for the Green Leaf Vegetable Indicator

The following table can serve as initial data for analyzing the green color of vegetable leaves. These are not absolute values, but rather an initial range that is physiologically plausible based on the HSV concept and the fact that leaf color, hue, chlorophyll, and nitrogen are interrelated.

TABLE I. INITIAL DATA FOR LEAF GREEN ANALYSIS

Leaf Color Categories	Hue 0–360°	Hue OpenCV 0–179	Assumed plant status	Physiological interpretation
Yellow/severe chlorosis	45–70°	23–35	Unhealthy/severe deficiency	Leaves are turning yellow; low chlorophyll levels—possibly due to nitrogen deficiency or severe stress.
Yellow-green	70–90°	35–45	Less healthy/mild-moderate deficiency	Leaves are beginning to fade; chlorophyll content is decreasing
Light green/pale green	90–105°	45–53	Adequate, but not yet optimal	The plant is still green, but the intensity of the green color is not yet strong.
Normal green	105–160°	53–80	Healthy / thriving ($V > 0.55$)	Green is the dominant leaf color and brightness is not reduced, indicating good chlorophyll levels.
Dark green	105–160°	53–80	Very green/adequate-high N ($0.40 \leq V \leq 0.55$)	Chlorophyll levels are relatively high; excess nitrogen, shading, or exposure can also lower Value.
Very dark green	105–160°	53–80	Possibly very high N ($V < 0.40$)	May indicate strong chlorophyll saturation, but may also result from shadow or underexposure; cross-check the pixel-validity ratio.

Leaf Color Categories	Hue 0–360°	Hue OpenCV 0–179	Assumed plant status	Physiological interpretation
Outside the green leaf range	<45 or >170°	<23 or >85	Invalid / noise	Possible causes include background, shadows, soil, polybags, or ROI errors

III. METHOD

A. Research Design and Scope

This study employs a Research and Development (R&D) approach limited to the development and simulation-based evaluation of an HMI application. The R&D approach was chosen because the primary output of the study is an application prototype, not agronomic data. The research phases include needs identification, system design, application development, creation of color simulation scenarios, program implementation, functional testing, computational verification, and evaluation of results. The scope of this study explicitly excludes crop cultivation trials, the acquisition of real leaf images in the field, SPAD measurements, chlorophyll content measurements, or leaf nitrogen analysis. Terms such as “normal green,” “pale green,” “greenish-yellow,” and “dark green” are used as simulated visual categories. Therefore, the classification results do not constitute an actual plant health diagnosis. Fig. 1 illustrates the stages of this research.

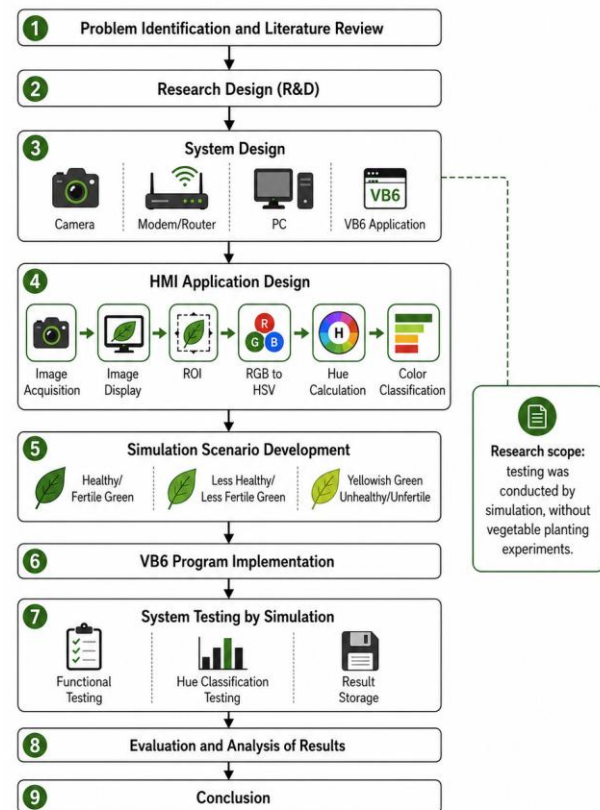


Fig. 1. Research design for the development of an HMI application for analyzing leaf greenness based on hue.

B. System Design

The system consists of a CCTV camera, a Wi-Fi modem/router, a PC, and an HMI application based on Visual Basic 6.0. The camera functions as an image acquisition device or visual input source. The modem/router serves as the communication medium between the camera and the PC. The PC runs the HMI application to display images, read RGB values, convert RGB to HSV, calculate hue, and display color categories in a simulated manner. The figure below shows the component setup. Fig. 2 shows a block diagram of the leaf green analysis system architecture, while Fig. 3 shows the system component setup. Table II lists the functions of each system component.

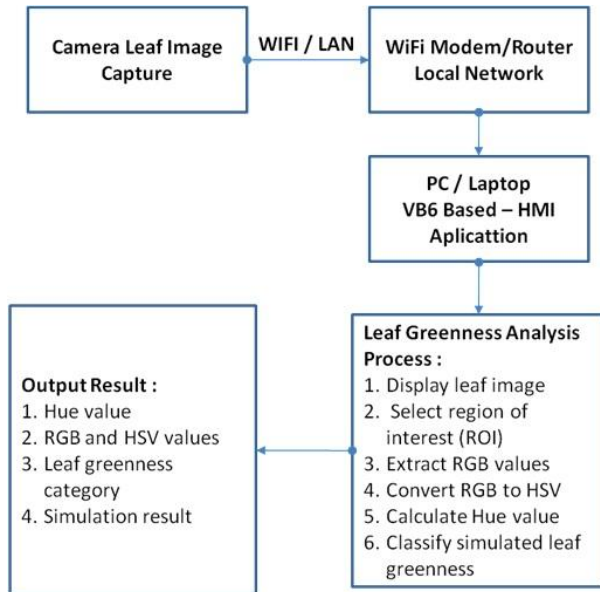


Fig. 2. System architecture block diagram.



Fig. 3. Concepts of configuring cameras, modems/routers, and data processing units.

TABLE II. FUNCTIONS OF SYSTEM COMPONENTS

Components	Functions
CCTV camera	Captures images or visual input for application testing.
Wi-Fi modem/router	Provides local communication between the camera and the PC.
PC/laptop	Runs the HMI application and performs color processing.
VB6 application	Loads images, extracts RGB values, converts to HSV, calculates hue, and displays simulated categories.

C. HMI Application Development

The HMI application was developed using Visual Basic 6.0. VB6 was chosen based on the availability of the programming environment and the ease of creating the user interface. Although VB6 is not a modern platform, this research remains relevant as an initial prototype and can be migrated in future research to Python, C#, or web-based applications. Table III shows the features included in the HMI, and Pseudocode 1 illustrates the pattern for building the HMI application program.

TABLE III. HMI APPLICATION FEATURES

HMI Module	Functions
Image acquisition/load	Capture or load an image/color sample.
Image display	Display the image in the PictureBox/HMI area.
ROI or area of analysis	Specify the color area to be analyzed.
RGB extraction	Read the R, G, and B values from the selected pixel.
HSV conversion	Convert RGB to Hue, Saturation, and Value.
Hue analysis	Calculate the average Hue as a color direction feature.
Classification	Assign a visual category based on Hue and Value rules.

Pseudocode 1. Methods for developing an HMI.

```
BEGIN PROGRAM

INITIALIZE HMI APPLICATION
Set image display area
Set RGB output fields
Set HSV output fields
Set Hue output field
Set leaf greenness category output
Set data storage folder
Set default status = "Ready"

WHILE application is running DO

    IF user clicks "Load Image" OR "Capture Image" THEN
        Acquire image from camera or file
        Display image on HMI
        Set image status = "Image loaded"
    END IF

    IF user clicks "Select ROI" THEN
        User selects leaf area or color area
        Save selected ROI coordinates
        Display selected ROI on image
        Set ROI status = "ROI selected"
    END IF

    IF user clicks "Process" THEN

        IF image is not loaded THEN
            Display warning message: "Please load image first"
            STOP processing
        END IF

        IF ROI is not selected THEN
            Display warning message: "Please select ROI first"
            STOP processing
        END IF

        Read all pixels inside the selected ROI

        SET total R = 0
```

```
SET total_G = 0
SET total_B = 0
SET total_Hue = 0
SET total_Saturation = 0
SET total_Value = 0
SET pixel_count = 0

FOR each pixel in ROI DO

    Read the RGB value of the pixel.
    R = Red value
    G = Green value
    B = Blue value

    Add R to total_R
    Add G to total_G
    Add B to total_B

    Normalize RGB values
    R' = R / 255
    G' = G / 255
    B' = B / 255

    Calculate Cmax
    Cmax = maximum value of R', G', B'

    Calculate Cmin
    Cmin = minimum value of R', G', B'

    Calculate Delta
    Delta = Cmax - Cmin

    Calculate Hue
    IF Delta = 0 THEN
        Hue = 0
    ELSE IF Cmax = R' THEN
        Hue = 60 × ((G' - B') / Delta)
        IF Hue < 0 THEN
            Hue = Hue + 360
        END IF
    ELSE IF Cmax = G' THEN
        Hue = 60 × (((B' - R') / Delta) + 2)
    ELSE IF Cmax = B' THEN
        Hue = 60 × (((R' - G') / Delta) + 4)
    END IF

    Calculate Saturation
    IF Cmax = 0 THEN
        Saturation = 0
    ELSE
        Saturation = Delta / Cmax
    END IF

    Calculate Value
    Value = Cmax

    Add Hue to total_Hue
    Add Saturation to total_Saturation
    Add Value to total_Value

    pixel_count = pixel_count + 1

END FOR

Calculate average RGB
average_R = total_R / pixel_count
average_G = total_G / pixel_count
average_B = total_B / pixel_count

Calculate average HSV
average_Hue = total_Hue / pixel_count
average_Saturation = total_Saturation / pixel_count
```

```
average_Value = total_Value / pixel_count

Classify leaf greenness based on average_Hue

IF average_Hue >= 45 AND average_Hue < 90 THEN
    category = "Yellowish green / unhealthy"
ELSE IF average_Hue >= 90 AND average_Hue < 105 THEN
    category = "Pale green / less healthy"
ELSE IF average_Hue >= 105 AND average_Hue <= 135 THEN
    category = "Healthy green"
ELSE IF average_Hue > 135 AND average_Hue <= 160 THEN
    category = "Dark green / strong green"
ELSE
    category = "Invalid or non-leaf color"
END IF

Display result on HMI
Show average_R
Show average_G
Show average_B
Show average_Hue
Show average_Saturation
Show average_Value
Show leaf greenness category

Set processing status = "Analysis completed"

END IF

IF user clicks "Save Result" THEN
    Save image
    Save ROI information
    Save average RGB values
    Save average HSV values
    Save Hue value
    Save leaf greenness category
    Display message: "Result saved successfully"
END IF

IF user clicks "Reset" THEN
    Clear image display
    Clear ROI selection
    Clear RGB output
    Clear HSV output
    Clear Hue output
    Clear category output
    Set status = "Ready"
END IF

IF user clicks "Exit" THEN
    Close application
END IF

END WHILE

END PROGRAM
```

D. RGB-to-HSV Conversion Algorithm

Each RGB pixel has R, G, and B values in the range of 0 to 255. Before being converted to HSV, these values are normalized to the range of 0 to 1 using Eq. (1). Afterward, the maximum, minimum, and chromatic difference values are calculated as shown in Eq. (2)- (4) [20].

$$R' = R/255, G' = G/255, B' = B/255 \quad (1)$$

$$Cmax = \max(R', G', B') \quad (2)$$

$$Cmin = \min(R', G', B') \quad (3)$$

$$\Delta = Cmax - Cmin \quad (4)$$

Hue is calculated according to the following rule:

- $H = 0$ if $\Delta = 0$;
- $H = 60 \times (((G' - B') / \Delta) \bmod 6)$, $C_{\max} = R'$
- $H = 60 \times (((B' - R') / \Delta) + 2)$, $C_{\max} = G'$
- $H = 60 \times (((R' - G') / \Delta) + 4)$, $C_{\max} = B'$

Moreover, Saturation is calculated as:

Saturation is defined as $S = 0$ when $C_{\max} = 0$, and $S = \Delta / C_{\max}$ otherwise. Value is defined as $V = C_{\max}$.

In this study, Hue is used as the primary feature for color direction. However, to avoid inconsistencies between light green and dark green, Value is used as a supporting attribute for brightness. Thus, color classification does not rely solely on Hue but also takes into account the darkness or brightness of the color. The categories “healthy,” “less healthy,” and “unhealthy” in this study are color-based simulation categories, not the result of physiological validation of the plants.

Furthermore, to ensure that value-based adjustments are explicit and reproducible, it is necessary to establish a formal classification rule that is applied consistently, as shown in Pseudocode 1 and in the verification example in the analysis section. Hue is assigned to each ROI as yellowish green ($45^\circ \leq H < 90^\circ$), pale green ($90^\circ \leq H < 105^\circ$), or green ($105^\circ \leq H \leq 160^\circ$). Within these green ranges, the average value is used to distinguish between normal green ($V > 0.55$), dark green ($0.40 \leq V \leq 0.55$), and very dark green ($V < 0.40$). Hue values in the range of $45\text{--}170^\circ$ are considered invalid or not leaf colors, as shown in Table I.

E. Simulation Data and Evaluation Scenarios

The simulation data was compiled from two sources: 1) color samples representing visual leaf scenarios, namely greenish-yellow, pale green, normal green, dark green, and very dark green; 2) standard green colors from CSS named colors as additional test data with documented RGB values. This data was used solely as a computational test fixture, not as physiological plant data.

Evaluation was conducted through three types of testing: 1) black-box testing of the application’s functionality; 2) algorithmic verification by comparing the application’s output Hue, Saturation, and Value values against reference calculations; and 3) classification consistency evaluation, which assesses the alignment of the application’s output with predefined simulated category rules. The metrics used were function success rate, absolute Hue error, and rule consistency accuracy. The absolute difference, in degrees, between the Hue result from the application and the reference value calculated using the RGB-to-HSV conversion formula.

IV. RESULT AND DISCUSSION

A. System and Application Implementation

The system implementation resulted in an HMI application prototype capable of loading images or color samples, displaying images on the interface, reading RGB values, converting RGB to HSV, calculating Hue, Saturation, and Value, and displaying color categories. This application is

designed as a preliminary analysis tool that can be further developed using real leaf images once measurement and data collection facilities are available.

B. Results of Black-Box Functional Testing

Fig. 4 shows the display of the Leaf Green Analysis HMI, while Table IV shows that all tested functions operated as designed. The function success rate was 8 out of 8, or 100%. This value indicates the functional success of the software, not the physiological accuracy of the plant.

TABLE IV. RESULTS OF BLACK-BOX FUNCTIONAL TESTING

No	Test Scenario	Expected Results	Observation Results	Status
1	Open the application	The main HMI form appears	Displayed	Passed
2	Load/retrieve an image	The image appears on the HMI	Displayed	Passed
3	Select the analysis area	The selected color area is highlighted	Detected	Passed
4	RGB extraction	The R, G, and B values are displayed	Appears	Passed
5	HSV conversion	Hue, Saturation, and Value are displayed	Appears	Passed
6	Color classification	The simulation category is displayed	Displayed	Passed
7	Save results	The results are saved	Saved	Passed
8	Process without an image/ROI	The application displays a warning	Warning displayed	Passed

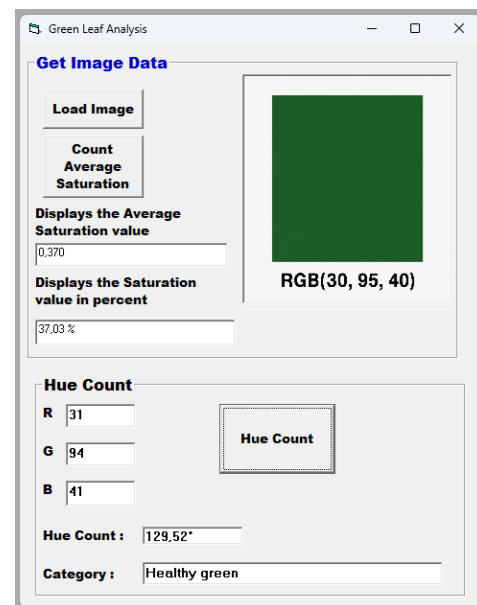


Fig. 4. HMI display: Leaf green analysis.

Fig. 4 shows the interface of the Green Leaf Analysis application, which was developed to analyze leaf green color based on RGB and HSV values. In this application, users can upload an image or a leaf color sample, and the program then reads the color values in RGB format. The example in the figure shows a color sample with RGB values of (30, 95, 40). Once the RGB values are obtained, the program calculates the Average

Saturation value, the Saturation value in percent, and the Hue value. The analysis results are then displayed as a leaf color category, namely "Healthy Green."

Thus, this application functions as a simple HMI to assist in the simulation of leaf greenness analysis based on digital color features. To obtain the HSV values, follow these steps:

1) The initial values read from the image are: $R = 30$, $G = 95$, $B = 40$

a) Before being converted to HSV, the RGB values are normalized from the range 0–255 to 0–1:

- $R! = (30 / 255) = 0.1176$
- $G! = (95 / 255) = 0.3725$
- $B! = (40 / 255) = 0.1569$

b) Next, find the largest value, the smallest value, and the difference between them:

- $C_{\max} = 0.3725$
- $C_{\min} = 0.1176$
- $\Delta = C_{\max} - C_{\min} = 0.2549$

c) Since the largest value is $G!$, the Hue formula used is:

- $H = 60^\circ \times ((B! - R!) / \Delta) + 2$
- $H = 60^\circ \times (((0.1569 - 0.1176) / 0.2549) + 2)$
- $H = 60^\circ \times 2.154$
- $H = 129.23^\circ$

d) So the Hue value is approximately: $H \approx 129.52^\circ$

This value falls within the green range, so the app classifies it as "Healthy Green."

2) Calculating saturation:

- $S = \Delta / C_{\max}$
- $S = 0.2549 / 0.3725 = 0.684$

If expressed as a percentage: $S = 0.684 \times 100 = 68.4\%$. This value indicates that the green color in the sample is quite strong—not too pale.

3) Calculating value, which indicates the brightness of a color:

- $V = C_{\max}$
- $V = 0.3725$
- $V = 0.3725 \times 100 = 37.25\%$

This means that the color is classified as very dark green because its brightness level is not very high.

C. Algorithmic Verification of RGB to HSV

Algorithmic verification was performed by calculating the HSV values of RGB samples using the reference formula and then comparing them with the application's output. Table V shows the reference values used as the basis for testing. Since the color categories are simulated, the evaluation reported here focuses on the consistency of the algorithm and classification rules, not the accuracy of plant diagnosis.

As additional test data, several sRGB standard colors from CSS named colors were used to verify the consistency of the calculations with the documented RGB values. Table VI shows these color fixtures.

TABLE V. KEY SIMULATION SAMPLES AND THE RESULTS OF CONVERTING RGB TO HSV

Sample	Simulation category	R	G	B	Hue (degrees)	Saturation	Value	Color scale
S1	Greenish-yellow	145	160	55	68.57	0.656	0.627	Greenish-yellow
S2	Pale green	115	165	75	93.33	0.545	0.647	Pale green
S3	Normal green	70	150	55	110.53	0.633	0.588	Normal green
S4	Dark green	45	120	50	124.00	0.625	0.471	Dark green
S5	Very dark green	30	95	40	129.23	0.684	0.373	Very dark green

TABLE VI. SRGB/CSS COLOR FIXTURES FOR ADDITIONAL TESTING

Sample	Color names	RGB	Hue	Saturation	Value	Rule output
S6	ForestGreen CSS	RGB(34, 139, 34)	120.00	0.755	0.545	Dark green
S7	YellowGreen CSS	RGB(154, 205, 50)	79.74	0.756	0.804	Greenish yellow
S8	PaleGreen CSS	RGB(152, 251, 152)	120.00	0.394	0.984	Normal green
S9	DarkGreen CSS	RGB(0, 100, 0)	120.00	1.000	0.392	Very dark green
S10	OliveDrab CSS	RGB(107, 142, 35)	79.63	0.754	0.557	Greenish yellow
S11	LightGreen CSS	RGB(144, 238, 144)	120.00	0.395	0.933	Normal green
S12	Green CSS	RGB(0, 128, 0)	120.00	1.000	0.502	Dark green

D. Computational Comparison with RGB-Based Indices

In addition, simulation samples were also calculated using commonly used RGB-based indices, namely ExG, NGRDI, and the G/R ratio. This comparison is not intended as agronomic validation, but rather to demonstrate that the application can be developed to utilize not only Hue but also other color indices in future research. Moreover, the computational comparison of Hue with RGB-Based Indices on a Set of Key Simulation Samples is shown in Table VII.

TABLE VII. A COMPUTATIONAL COMPARISON OF HUE WITH RGB-BASED INDICES ON A SET OF KEY SIMULATION SAMPLES

Sample	R	G	B	ExG	NGRDI	G/R
S1	145	160	55	0.333	0.049	1.10
S2	115	165	75	0.394	0.179	1.43
S3	70	150	55	0.636	0.364	2.14
S4	45	120	50	0.674	0.455	2.67
S5	30	95	40	0.727	0.520	3.17

E. Discussion

The test results show that the VB6-based HMI application can perform basic leaf color analysis processes in a simulated environment. The application's main outputs include RGB values, hue, saturation, value, and color categories. Thus, this application can serve as an initial prototype to support digital image-based leaf greenness analysis. This research does not claim to provide physiological plant diagnoses; categories such as greenish-yellow, pale green, normal green, and dark green are visual categories based on color values. The research results are based on software evaluation and color simulation. Using Hue alone has limitations; some shades of normal green and dark green may have similar Hue values but differ in Value and Saturation. Therefore, Saturation and Value can be used as supporting attributes. Simulation results show that dark green is more accurately distinguished by a lower Value rather than solely by an increase in Hue. This addresses the inconsistencies in Hue classification found in previous versions of the manuscript.

Compared to the ExG index, NGRDI, and G/R ratio, Hue is easier to use for indicating color direction, while the RGB index better reflects the dominance of the green channel over the other channels. Since each feature carries different information, future research could combine Hue, Saturation, Value, ExG, NGRDI, and G/R to improve classification robustness once real-world leaf data becomes available. A limitation of this study is the use of simulated data; although simulated data is suitable for testing program logic, the results do not yet prove that the application can detect plant fertility or health in the field. Factors such as lighting, shadows, white balance, camera type, camera distance, and variations in leaf surface can alter RGB and HSV values. Therefore, this application should be positioned as an initial platform ready for validation in future research.

F. Implications of the Innovation and Limitations of Novelty

The innovation implications of this research are the availability of an HMI application design that can be used as an initial tool for education, demonstration, and testing of leaf color

analysis logic. This application separates the contribution of the software from claims regarding plant physiology, thereby making the scope of the research clearer and more measurable. This approach is relevant for situations where researchers do not yet have a chlorophyll meter, SPAD meter, or real leaf dataset, but still wish to build the foundation for a computationally testable image analysis system.

A limitation of this study's novelty is that the classifications of "healthy," "less healthy," and "unhealthy" are still visual-simulatory in nature. Hue values cannot yet be used for actual plant health diagnosis without physiological validation. Additionally, the implementation in Visual Basic 6.0 is legacy; therefore, further research is recommended to migrate the algorithm to Python, C#, or web-based applications, as well as to incorporate validation using real leaf images, controlled lighting conditions, and additional features such as Saturation, Value, texture, or simple machine learning models.

V. CONCLUSION

This study produced a Visual Basic 6.0-based HMI application prototype to support the simulated analysis of leaf greenness using the Hue feature in the HSV color space. The application is capable of loading or capturing images, displaying images, reading RGB values, converting RGB to HSV, calculating Hue, Saturation, and Value, and assigning color categories based on simulated rules.

Black-box testing showed that all the application's main functions operated as designed with a 100% success rate in the tested scenarios. Algorithmic verification demonstrated that the classification output followed the established rules based on Hue and Value values. However, the results of this study only demonstrate the application's functional and computational feasibility, not the physiological validation of the plants.

Further research is needed to incorporate real leaf images, lighting controls, camera variations, and reference data such as SPAD, chlorophyll, leaf nitrogen, or expert assessments. Additionally, the application could be redeveloped using a more modern platform and combined with features such as Saturation, Value, texture, ExG, NGRDI, G/R ratio, or simple machine learning methods.

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