A Novel Method for Optimizing Color Selection Using the Hadamard Product Technique

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IEEE 20230918.docx	Main Document - MS Word	2.4 MB
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Abstract

Numerous research endeavors have employed the color selection procedure for a vast array of purposes. Detecting defects in fabrics, calculating the Microbial Community Color Index, analyzing digital color in facilitating fashion design processes and applying color to artworks, calculating canopy cover, and achieving other objectives have been the subject of research. This procedure necessitates intricate steps, intricate calculations, and lengthy computational time. In this study, a novel strategy for optimizing the color selection process using the Hadamard product technique is presented. The HSV color space is optimized by selectively selecting the desired colors and establishing threshold limits for each hue, saturation, and value component. The optimization results demonstrate that the desired colors are perfectly distinguished from other colors. Additionally, the proposed method employs a straightforward, step-by-step procedure that does not require feature extraction. In comparison to previous research, a remarkable increase in computational speed of 1,078.82 times faster has been observed. This improvement is achieved by multiplying each element of the HSV matrix resulting from color selection as opposed to the HSV matrix without selection. This study's findings are applicable not only to plant images but also to all cases requiring color selection under visible light conditions.

Authors

Title	Name	Email	Country/Locatio
Mr.	**Toni Kusnandar** [1] Corresponding Author 0000-0002-8151-3689	33220008@mahasiswa.itb.ac.id	Indonesia
Dr.	**Judhi Santoso** [1]	judhi@itb.ac.id	Indonesia
Prof.	**Kridanto Surendro** [1]	endro@itb.ac.id	Indonesia

Affiliations

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- Image color analysis

- Image processing

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In this study, a novel strategy for optimizing the color selection process using the Hadamard product technique is presented. The optimization results demonstrate that the desired colors are perfectly distinguished from other colors. Additionally, the proposed method employs a straightforward, step-by-step procedure that does not require feature extraction. In comparison to previous research, a remarkable increase in computational speed of 1,078.82 times faster has been observed. This study's findings are applicable not only to plant images but also to all cases requiring color selection under visible light conditions.

Scope

This article is very interesting to readers because it describes a simple, accurate, and fast color selection process. Using ordinary visible-light cameras or UAV cameras, the proposed method can be implemented in agriculture and other fields requiring rapid color selection.

Unique Contribution

In this research, a novel approach employing the Hadamard Product technique was used to optimize the Color Sselection procedure. In the HSV, optimization is done by choosing the desired colors with the Heaviside Step Function, which involves setting threshold values for each hue, saturation, and value. The proposed method involves element-wise matrix multiplication utilizing the Hadamard Product technique between the matrix resulting from the conversion to HSV without selection and the matrix resulting from the conversion with selection. The optimization results indicate that the desired colors have been successfully separated from other colors.

History

Submitted On	19 September 2023 by Toni Kusnandar
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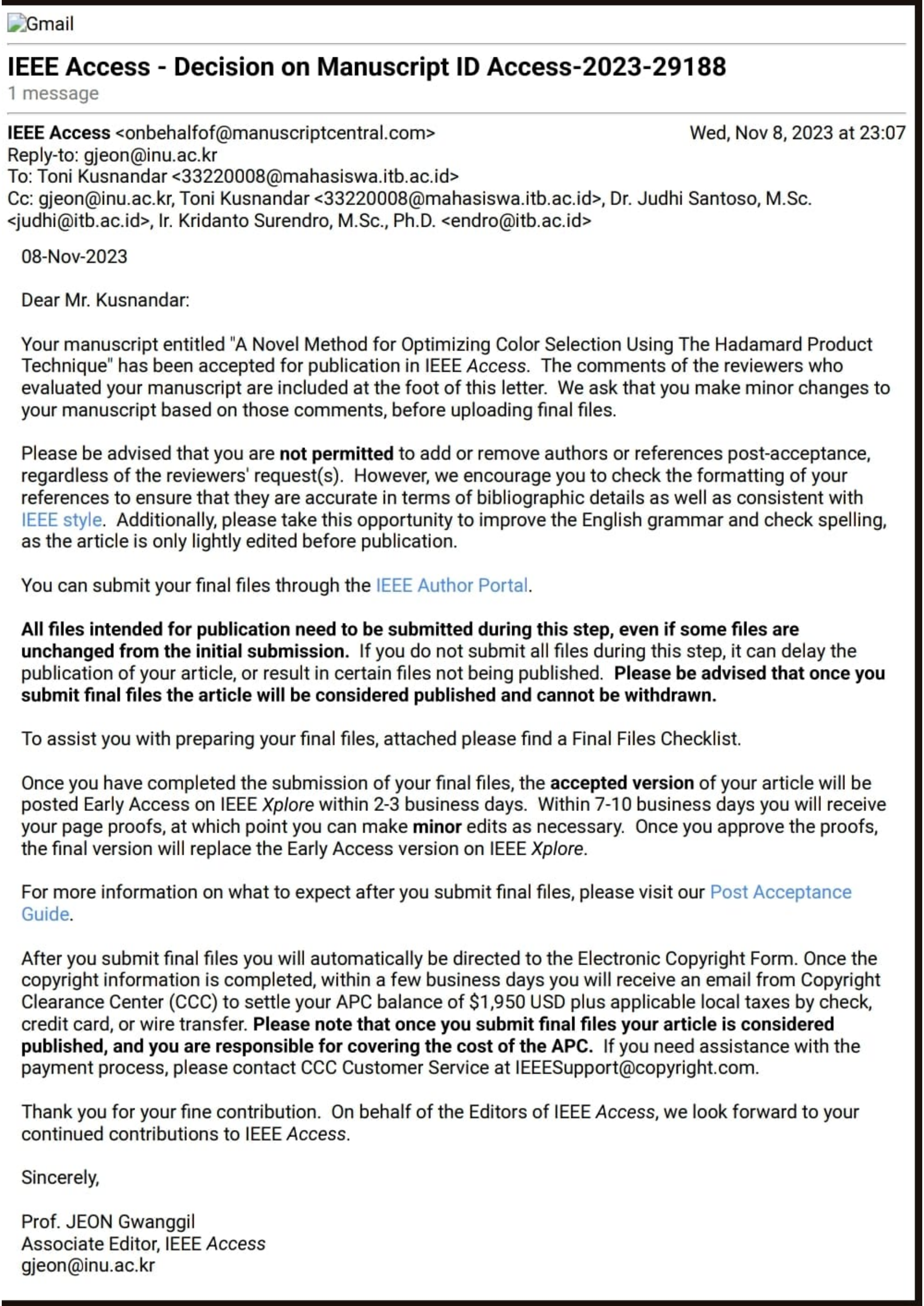

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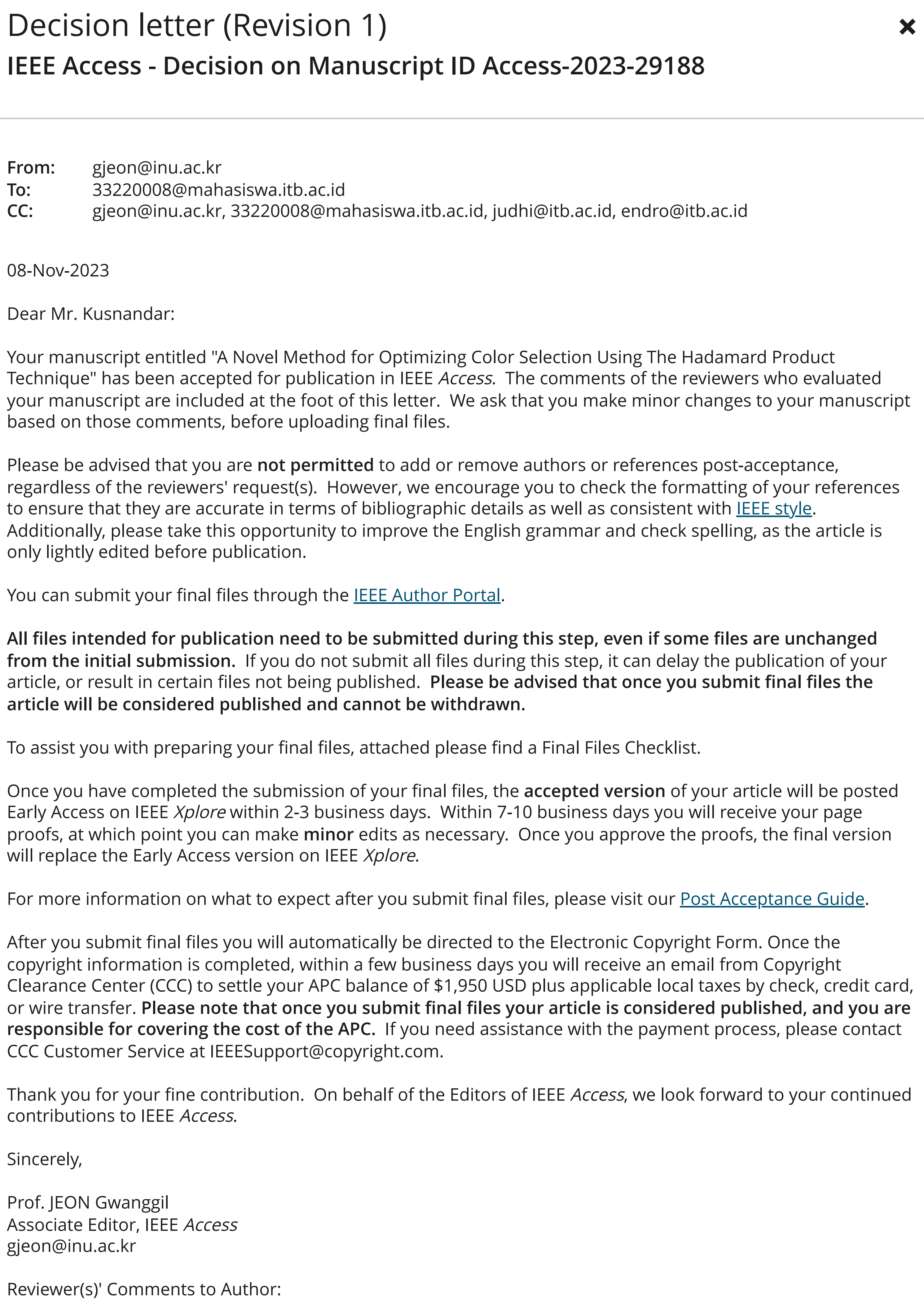

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2. Offer more specific details regarding the applications of the Hadamard product method and how it improves upon previous methods.
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7. Expand on how the optimization process was carried out. Describe the HSF technique and HDP method, their roles, and how they contribute to the optimization.
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A Novel Method for Optimizing Color Selection Using The Hadamard Product Technique

Toni Kusnandar[1], Judhi Santoso[2], and Kridanto Surendro[3]
[1]School of Electrical Engineering and Informatic, Institut Teknologi Bandung, Jl Ganesha 10, Bandung, Indonesia.

Corresponding author: Toni Kusnandar (e-mail: 33220008@mahasiswa.itb.ac.id).

ABSTRACT Numerous research endeavors have employed the color selection procedure for a vast array of purposes. Detecting defects in fabrics, calculating the Microbial Community Color Index, analyzing digital color in facilitating fashion design processes and applying color to artworks, calculating canopy cover, and achieving other objectives have been the subject of research. This procedure necessitates intricate steps, intricate calculations, and lengthy computational time. In this study, a novel strategy for optimizing the color selection process using the Hadamard product technique is presented. The HSV color space is optimized by selectively selecting the desired colors and establishing threshold limits for each hue, saturation, and value component. The optimization results demonstrate that the desired colors are perfectly distinguished from other colors. Additionally, the proposed method employs a straightforward, step-by-step procedure that does not require feature extraction. In comparison to previous research, a remarkable increase in computational speed of 99.91 percent has been observed. This improvement is achieved by multiplying each element of the HSV matrix resulting from color selection as opposed to the HSV matrix without selection. This study's findings are applicable not only to plant images but also to all cases requiring color selection under visible light conditions.

INDEX TERMS Color Selection, Color Space, Hadamard Product, Heaviside Step Function

I. INTRODUCTION

The color selection method has been utilized in numerous research studies for a wide variety of purposes. Utilizing color selection techniques to address issues of noise and blurriness in original fabric images, research has been conducted to detect defects in fabrics. Enhancing the contrast between flaws and the background is the strategy. Utilized preprocessing methods include color space conversion, Gaussian filtering, saliency map generation, and contrast stretching [1]. In addition, color selection processes are used to calculate the Microbial Community Color Index (MCCI). Analyzing images involves considering circular regions of varying diameters. At each pixel, the RGB channel intensities (red, green, and blue) are extracted to generate an artificial color scale resembling the original filter colors. This fabricated scale is then used to calculate the MCCI [2]. Color selection is also performed for digital color analysis in order to facilitate the fashion design process and the use of artistic colors in fashion product design [3].

This study improves upon an earlier one that used only the hue parameter to select green in the HSV color space from plant images [4]. Due to the separation of color channels, intensity channels, and saturation channels, the HSV color space is still used for this optimization. Given that a key characteristic of healthy photosynthesis is increased green reflectance [5]–[7], this study begins by filtering only green light. The median hue value for green is approximately 120°, but for the purposes of this study, the hue range 90° to 150° is selected. The heavyside step function is utilized during the color separation procedure in the HSV color space (HSF). The optimization results for choosing green or other colors are flawless, as no undesirable hues are retained.

In addition, this optimization drastically reduces the computational time, from two to three minutes to just 0.2 to 0.3 seconds. This increase in computational speed is accomplished by implementing the HSF method via element-wise multiplication with the Haddard Product (HP) technique.

II. RELATED WORKS

Fractional green canopy cover (FGCC) has become a non-destructive and easy-to-measure variable that is used in fields like ecology, environmental science, and agronomy to measure active vegetative land cover at different spatial and temporal scales. Canopeo is a program that uses the Automatic Color Threshold (ACT) algorithm, which was made in the Matlab programming language and uses RGB color values (MathWorks, Inc., Natick, MA).Canopeo analyzes and categorizes every pixel in an image based on the R/G, B/G, and excess green index ratios. Canopeo can find FGCC faster and more accurately than the other software packages that were looked at in this study.However, Canopeo has some limitations. It necessitates keeping the camera above the canopy. For vegetation exceeding 2.5 meters in height, aerial photographs or specialized equipment are required. Combining the excess green index with the R/G and B/G ratios to spot other components in digital images is an area in need of more research [8].

Córcoles et al. conducted an experiment to derive canopy cover (CC) measurements from UAV-collected images. The obtained images were analyzed in order to differentiate the green color of plants from colors representing soil, shadows, and rocks. The k-means method was used to analyze color clusters during image processing, necessitating the transformation of RGB images into the L*a*b* color space. The plant images were adequately separated from soil, shadows, rocks, and other elements, as determined by visual inspection. However, this process becomes less computationally efficient when applied to the entire image. In order to circumvent this computational inefficiency, only the selected portions of the image were utilized [9].

Scientists worldwide are interested in plant harvesting for monitoring farms, forests, and other locations. The GLI is the best vegetation index for all case studies, as it looks at all visible spectrum bands captured by RGB cameras. This index consistently provides better results than other ones, regardless of the situation. However, the way each index works in each case study is different, so there is a better index for each unique orthophoto that shows where there is vegetation. The results of this study can be used with any RGB orthophoto, whether taken from the ground or from the air [10].

In a perfect world, the results of vegetation indices (VI) would not be affected by changes in illumination and would accurately reflect the true state of plant conditions. Automatic multiresolution Retinex correction can help reduce the effects of lighting changes in color images captured by UAVs during flights on cloudy days. When the multivariate linear model is built using the five most important top VIs, this correction process enhances the model's performance [11]. The method to correct uneven contrast and luminosity has also been applied to fundus images, which have been processed in five steps: image input, selection, luminosity correction, histogram stretching, and post-processing. Through one-dimensional lowpass filtering, a Luminosity Surface Smooth (LS) is constructed from the region of interest (ROI) in this method (1DLF). This method effectively reduces uneven luminance and increases contrast in fundus images affected by reflections [12].

The colors we see come from light waves that are reflected by objects. The source of the light and the way the objects reflect light affect the colors we see [13]. In studies of the perfect reflectance method, it has been determined that accurate reflectance data is generated by objects with effective light reflection [14]. The light reflectance or light intensity of digital images can be determined by using a variety of color spaces, which are mathematical representations of sets of colors. These representations can be used. All color spaces are derived from the red, green, and blue (RGB) data provided by devices like cameras and scanners. RGB is the most popular color space for computer images due to the fact that red, green, and blue can be used to create any desired color [6].

The transformation of color spaces is a fundamental aspect of image processing and a crucial aspect of observing the real world through camera equipment [15], [16]. The objective of the transformation of color spaces is to faithfully reproduce the data that was collected from the physical world without making any changes to the data itself. The veracity of real images can be reproduced with the help of a variety of color space models, and the appropriate data can be extracted from them based on the application. Therefore, the requirement for color space transformation is crucial [15]. However, such transformations frequently result in the loss of information. Some examples of color space transformations that result in loss of information include printing in grayscale, converting multispectral or multiprimary data to tristimulus space, and converting between color gamuts [17].

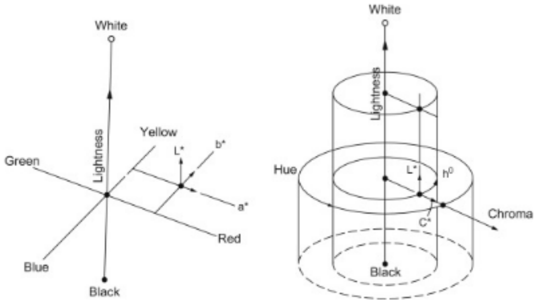


FIGURE 1. A three-dimensional graph depicting the brightness, chroma, and hue of actual surface colors [18]

Color space systems can precisely describe color stimuli. Multiple color systems, including RGB, CMYK, and CIELAB, are utilized. FIGURE 1 depicts a three-dimensional representation of a color space with luminance along one axis, chroma along another axis, and a hue circle where hue is measured in degrees. This configuration provides a reasonable color scale in terms of luminance and chroma, while scaling along the hue circle is relatively consistent [18].

Element-wise multiplication, also known as Hadamard Product (HP), is an often-overlooked concept in matrix theory for element-by-element multiplication [19], [20]. Element-by-element matrix multiplication is fundamental in matrix computations, especially in matrix differentials, with Hadamard Product being a notable example [21]. Due to the element-by-element nature of the multiplication, matrices must be of identical size when employing this operation [19].

In the past few decades, dehazing images has become an intriguing area of study within the computer vision community. Recently, image dehazing techniques based on deep learning have matured and become more trustworthy, demonstrating remarkable performance. A novel HP model consisting of data-driven priors and employing the Learnable Hadamard-Product-Propagation (LHPP) technique has been proposed. This method mitigates noise and artifacts during the restoration process, resulting in optimal output [22].

The use of drones, also known as unmanned aerial vehicles (UAVs), provides significant benefits to precision agriculture by reducing labor needs and achieving significant time savings [23], [24]. UAV image capture is more effective and user-friendly [25]. By providing quick calculations and enabling real-time identification processes, the proposed method will bolster the advantages of UAV use in agriculture.

III. PROPOSED METHOD

The color green that plants reflect is one of the indicators of healthy photosynthesis [5], [7], [26]. Therefore, this study begins by filtering only the green color, extending the findings of prior research by doing so [4]. To prevent erroneous identification of plants against a bright background, a minimum saturation threshold must be established. Also, a minimum intensity (value) can be set to keep dark pixels from being wrongly labeled. It is possible to change hue, saturation, and value to fit different species [27].

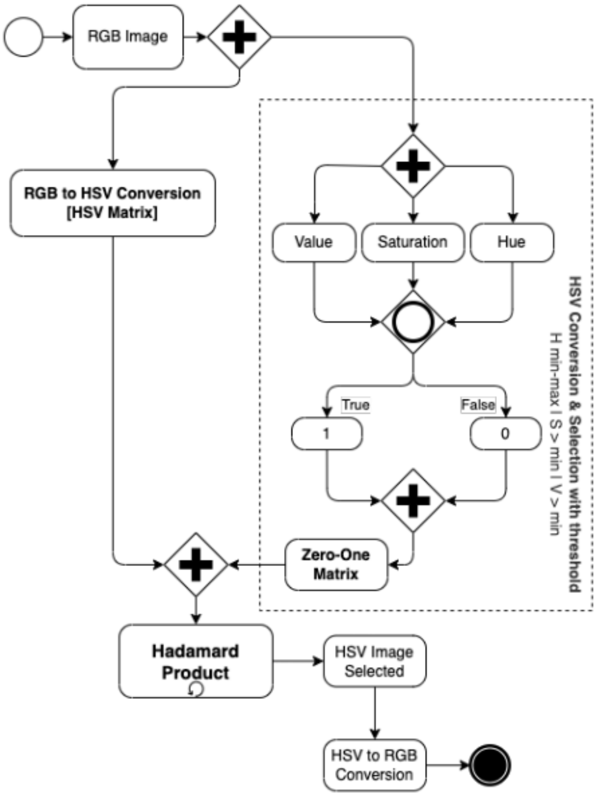


FIGURE 2. Proposed Method for Color Selection using Hadamard Product Technique

In this investigation, a novel approach employing the HP technique was used to optimize the color selection procedure. In the HSV color space, optimization is done by choosing the desired colors with the Heaviside step function (HSF), which involves setting threshold values for each hue, saturation, and value. The proposed method involves element-wise matrix multiplication utilizing the HP technique between the matrix resulting from the conversion to HSV without selection and the matrix resulting from the conversion with selection. The optimization results indicate that the desired colors have been successfully separated from other colors. By adjusting the threshold values for hue, saturation, and intensity/value, the proposed method, as depicted in FIGURE 2, can also be utilized to select various desired colors.

IV. EXPERIMENT RESULT & DISCUSSION

In the initial study, an experiment was conducted to select green leaf colors from images of plants. A change from RGB to HSV was made to separate the color channels from the channels for intensity and saturation. The initial experiment involved filtering green hue values between 90 and 150. The results of the experiment demonstrated the successful separation of green leaf colors, although there were instances in which certain components of the green color were not entirely separated [4]. Incorporating two additional parameters, saturation and intensity/value, an optimization was conducted based on these experimental findings. Because the unselected green colors exhibited varying intensities and saturations, saturation and intensity were introduced as additional parameters. Experimenting with different threshold values for saturation and intensity was part of the procedure. Experiments were conducted for the selection of green colors within the wavelength range of 500 nm to 600 nm in this study. During the RGB to HSV image conversion, the green color was chosen with a hue range of 90° to 150°, saturation > 90, and intensity or value > 85.

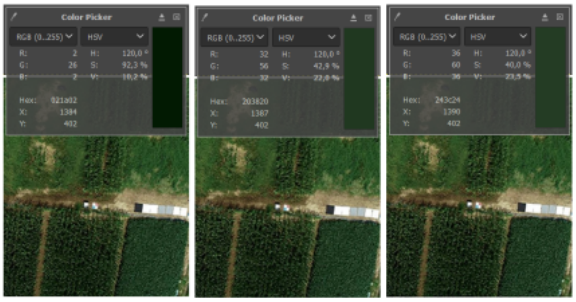
A. COLOR SPACE CONVERSION

In order to separate the hue/color channel from the saturation and value channels, the RGB color space was changed into the HSV color space. Due to the inconsistency of RGB images in providing color values in comparison to HSV images, color conversion was required. In FIGURE 3 and Table 1, the hue value of the green color in the RGB image varies, whereas the hue value remains constant at 120° in the HSV image. There are distinct R, G, and B values for the green hue in each of the three images, resulting in distinguishable color differences. In contrast, the hue value in the HSV color space remains constant while the S and V values vary.

Table 1. Comparison of RGB with HSV

Chanel	Image 1	Image 2	Image 3
R	2	32	36
G	26	56	60
B	2	32	36

Chanel	Image 1	Image 2	Image 3
H	120,0°	120,0°	120,0°
S	92,3	42,9%	40,0%
V	10,2%	22,0%	23,5%



Color Picker
RGB (0..255) HSV
R: 2 H: 120,0 °
G: 26 S: 92,3 %
B: 2 V: 10,2 %
Hex: 021a02
X: 1384
Y: 402

Color Picker
RGB (0..255) HSV
R: 32 H: 120,0 °
G: 56 S: 42,9 %
B: 32 V: 22,0 %
Hex: 203820
X: 1387
Y: 402

Color Picker
RGB (0..255) HSV
R: 36 H: 120,0 °
G: 60 S: 40,0 %
B: 36 V: 23,5 %
Hex: 243c24
X: 1390
Y: 402

FIGURE 3. Comparison of RGB and HSV color value consistency

The RGB image's R, G, and B values are first normalized before being converted to HSV. For each RGB image, we can get its r (1), g (2), and b (3) values by first normalizing each individual pixel [28]:

$$r = \frac{R}{R+G+B} \tag{1}$$

$$g = \frac{G}{R+G+B} \tag{2}$$

$$b = \frac{B}{R+G+B} \tag{3}$$

$$V = max(r,g,b) \tag{4}$$

$$S = \begin{cases} 0 & if\ V = 0 \\ V - \frac{min(r,g,b)}{V} & if\ V > 0 \end{cases} \tag{5}$$

$$H = \begin{cases} 0 & if\ S{=}0 \\ 60^o \times \left[\frac{g-b}{S\times V}\right] & if\ V{=}r \\ 60^o \times \left[2+\frac{b-r}{S\times V}\right] & if\ max{=}g \\ 60^o \times \left[4+\frac{r-g}{S\times V}\right] & if\ max{=}b \\ H+360^o & if\ H{<}0 \end{cases} \tag{6}$$

B. COLOR SELECTION

Color selection is carried out by applying criteria in which the hue value falls between 90° (the lower hue threshold) and 150° (the upper hue threshold), and where the lower saturation threshold is set to 90 and the lower value threshold is set to 85. Using the heavy side step function, the threshold values are implemented (HSF). According to the desired color range, the hue, saturation, and value ranges of each image can be modified. The following formula can be used to express the equation for color selection using the HSF:

$$\mathcal{H}(H_o - H_{min}) \tag{7}$$

$$\mathcal{H}(H_{max} - H_o) \tag{8}$$

$$H = H_o \times \left(\mathcal{H}(H_o - H_{min}) - \mathcal{H}(H_{max} - H_o)\right) \tag{9}$$

$$S_o = \mathcal{H}(S_o - S_{min}) \tag{10}$$

$$V_o = \mathcal{H}(V_o - V_{min}) \tag{11}$$

Calculating the difference between the minimum hue value (7) and the maximum hue value (8) is the first step in arriving at the desired hue range (9). (8). In the meantime, both the saturation threshold value (10) and the value threshold value (11) are independently set. The ultimate equation looks like this in order to generalize the formula so that it can be applied to a wide variety of different hue, saturation, and value criteria:

$$SelectionHSV(H_o, S_o, V_o) = H_o \times \left(\mathcal{H}(H_o - H_{min}) - \mathcal{H}(H_{max} - H_o)\right) \times \mathcal{H}(S_o - S_{min}) \times \mathcal{H}(V_o - V_{min}) \tag{12}$$

where:

$$\mathcal{H}_{(x)} = \begin{cases} 0, & x < 0, \\ 1, & x \geq 0 \end{cases} \tag{13}$$

$$0^o \leq H_o \leq 360^0 \tag{14}$$

$$0 \leq S_o \leq 255 \tag{15}$$

$$0 \leq V_o \leq 255 \tag{16}$$

where:

H_{min} = Hue lower threshold value
H_{max} = Hue upper threshold value
S_{min} = Saturation lower threshold value
V_{min} = Value/Intensity lower threshold value

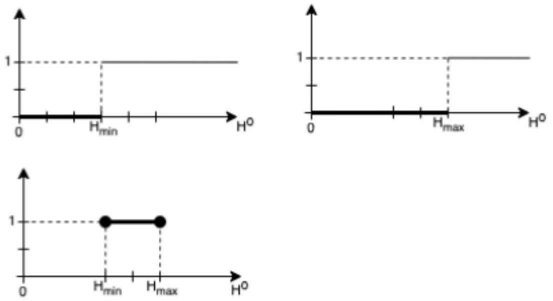


FIGURE 4. Hue threshold values

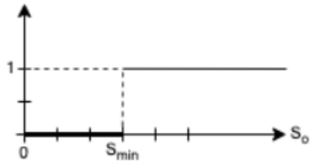


FIGURE 5. Saturation threshold value

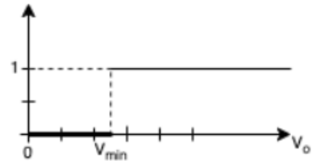


FIGURE 6. **Intensity/Value threshold value**

HSF threshold values of Hue, Saturation and Value can be depicted in FIGURE 4, FIGURE 5 and FIGURE 6.

C. HADAMARD PRODUCT TECHNIQUE

The conversion results with color selection are stored as zero-one matrices, while the conversion results without selection are stored as HSV matrices. The zero-one matrix represents the outcome of color selection, which serves as a mask for the original image (HSV matrix), enabling the creation of an image with the selected colors.

$$\begin{aligned} Final &= A \odot B \\ &= \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \odot \begin{pmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{pmatrix} \\ &= \begin{pmatrix} a_{11} \cdot b_{11} & \cdots & a_{1n} \cdot b_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} \cdot b_{m1} & \cdots & a_{mn} \cdot b_{mn} \end{pmatrix} \end{aligned} \tag{17}$$

Multiplication of each matrix element with the HP technique between *the zero-one* matrix and *the HSV matrix will produce an* HSV selected image *(17)*.) The image matrix of color selection in the HSV color space is stored in the $\mathbf{A}_{(M,N)}$ matrix, while the converted image to HSV without selection is stored in the $\mathbf{B}_{(M,N)}$ matrix. The final matrix is stored on the $\mathbf{Final}_{(M,N)}$ matrix which is the HDP result of $\mathbf{A}_{(M,N)} \odot \mathbf{B}_{(M,N)}$. Reverse conversion from HSV color space to RGB color space is performed so that color selection results can be displayed.

D. RESULT

A dataset consisting of five (five) RGB images that were captured using a visible-light camera that was mounted on a UAV was utilized in the testing of the method that was proposed. The images had a resolution of approximately 12 megapixels on average [4].

Table 2. Dataset

No	Dataset	Prior	Propose	Delta	Hue	S	V	Performance
1	North Konawe Palm Land	03:34.65	00:00.22	03:34.43	100-130	90	75	99,90%
2	Ciwidey Cabbage Garden	03:43.45	00:00.25	03:43.25	80-140	60	75	99,91%
3	FSRD ITB Bandung	02:52.20	00:00.15	02:52.05	80-140	75	75	99,91%
4	ITB North Gate	04:22.40	00:00.20	04:22.20	80-140	70	70	99,92%
5	Cipularang Toll Road Km 88	04:00.02	00:00.19	03:59.82	80-130	60	75	99,92%
							Average	**99,91%**

As can be seen in Table 2, the implementation of the suggested strategy led to an increase in overall computational speed that was 99.91 percent more efficient. This speed increase was accomplished by modifying the algorithm that was being used, moving away from looping and towards matrix element multiplication utilizing the HDP technique.

The proposed method was also tested with the dataset from the research on Greenness Identification, which introduced an HSV decision tree-based approach requiring four steps. This was done in order to verify the accuracy of the proposed method [29]. In HSV decision tree-based research, four steps are required. To mitigate the effects of illumination, the RGB color space is converted to the HSV color space in the first step. The second step focuses on removing a significant portion of background pixels based on their hue values in comparison to those of green plants. Thirdly, pixels representing wheat straw with hue values that overlap young green leaves are eliminated based on hue, saturation, and value. In the final step, thresholding is utilized to obtain pixels that depict the greenness of corn plants.

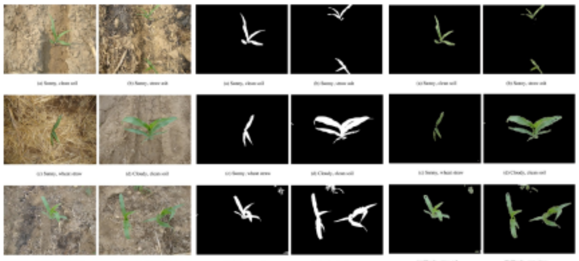


FIGURE 7. **Results of the comparison of the proposed method with the HSV decision tree**

FIGURE 7, depicts the results of the testing done on the proposed method for successfully selecting images of corn seedlings with a shorter process that maintains the same level of accuracy, instantly displaying the color green that they have. When utilizing the suggested approach, the necessary amount of time for processing is 0.009582 seconds when utilizing the given parameters H_{min}=70; H_{max}= 125, S_{min} = 15 dan V_{min} = 100.

V. CONCLUSION

By incorporating the parameters Saturation and Value, this research was able to successfully optimize the process of selecting a green color within the wavelength range of 500 nm to 600 nm or the hue range of 90° to 150°. This was accomplished within the context of the study. During the process of converting from the RGB color space to the HSV color space, the optimization was carried out with the help of the HSF technique and the HDP method. The optimization resulted in a significant improvement to the process of selecting colors by completely filtering out colors that were not desired. With the workflow being streamlined and the computational speed having been increased by 99.91 percent, the HSV color selection computation is now significantly faster than it was before. This strategy for optimizing the color selection process can be applied not only to the selection of the green color but also to the selection of any other color.

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