A Novel Color Feature for the Improvement of Pigment Spot Extraction in Iris Images

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***Abstract*—Feature extraction plays a vital role in the segmentation of regions of interest in medical images. While histograms offer a reliable method for analyzing color properties, the challenge of defining the pigment spot color has motivated the search for a practical feature for extraction. Consequently, analyzing the image using histograms and the HSV (Hue, Saturation, Value) color space led to the groundbreaking discovery of a reliable color feature and an exciting opportunity for pigment spot extraction. This study utilized 131 pigment spot images from the Miles Research datasets. The Region of Interest (ROI) was determined using a histogram color-based saturation intensity component, revealing new findings of thresholds ranging from 0.70 to 0.90. The results indicate that the proposed method achieved a Detection Rate (DR) of 37.1% (49 images), a False Acceptance Rate (FAR) of 14.5% (19 images), and a False Rejection Rate (FRR) of 48.4% (63 images). While the detection rate shows room for improvement, the proposed method significantly reduces the FAR to 14.5%, compared to 64.8% and 65.3% in color-based segmentation and simple color detection, respectively. This newfound feature contributes to improved accuracy and efficiency in medical image analysis, facilitating better patient diagnosis and treatment planning.**

***Keywords*— color feature, feature extraction, pigment spot, histogram, iris image**

I. INTRODUCTION

Feature extraction in medical imaging is a crucial process. Pigmentation on the iris surface serves as an indicator of an unhealthy iris, often associated with a melanocytic tumor [1]. In the worst-case scenario, such tumors can lead to blindness. However, the extraction process faces challenges due to the similarities in color and pattern between ciliary body melanoma and pigmentation spots. As a result, the accuracy of the extraction results is impacted.

In general, color histogram and thresholding methods are the conventional method used to deal with color image. One of the limitations encountered in the color histogram method's is inability to identify the specific color features of pigmentation effectively. The situation occur when iris surface color contains a similar color as the spot. Hence, the combination of Red, Green and Blue (RGB) in the color properties unable to be used to detect the accurate position or location of the spot on the iris surface. This leads to inaccurate extraction results. Moreover, the method performs poorly when dealing with small pigmentation spots [2]. These challenges highlight the need for improved extraction techniques in medical imaging, particularly when it comes to identifying pigmentation on the iris surface accurately.

Furthermore, the pigmentation spot can potentially be extracted by employing a threshold method to distinguish between the spot color and the foreground color. However, a challenge arises when the pixel in the spot color is the same or lighter than the foreground color, resulting in the creation of holes that need to be filled through image post-processing. Unfortunately, this post-processing leads to inaccurate results. Consequently, the major drawback highlighted in this context is the inaccurate extraction

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resulting from the difficulty in differentiating the specific pigmentation color [3].

Considering the preceding discussion, the critical concern that draws attention is the lack of an identified color feature to extract the pigmentation spot effectively and accurately detect the spot's location on the iris surface. Therefore, this study had to propose an improvement on the colour histogram method using the Hue, Saturation and Value (HSV) colour space in order to determine and filter the key colour feature, which is reliable to be used as a spot feature. The improvement conducted on the range of the colour threshold algorithm. Consequently, the main focus of this study is to discover a reliable color feature that can serve as an effective tool for pigment spot extraction.

In light of this study's aim, the paper's structure is organized as follows: Section II will provide a literature review and a discussion on related work. Section III will present the proposed method. Section IV will delve into the testing of the method and engage in detailed discussions. Finally, Section V will conclude the study's findings, and future recommendations for further research will be proposed in the same section.

II. Literature Review

Color histogram is a standard method used to analyze and segment the color in the image [4]. The method will represent the color frequency distribution of color bins in the image as a global feature and the spatial distribution of pixels as a local feature. However, color histograms lack complementary spatial information [4, 5]. Furthermore, working with the global color feature histogram intersection method is a better approach to be used. The method is reliable based on the selected color space, such as HSV or Gaussian blurred in Commission Internationale de l´Eclairage L*A*B* (CIELAB) color spaces [6]. Three color components have increased the performance of the method. However, the large number of bins describing the image has increased the feature vector of the descriptor dimension, and it has reduced the performance of the method.

Moreover, there is increased computational complexity. Aside from a lack of complementary spatial information, the color histogram method produces low-quality segmentation results due to irregularities and sharp details [7]. Furthermore, the method is computationally expensive because the number of threshold levels tends to boost complexity.

As part of a color histogram, there are several approaches exist to analyze and segment the color and retrieve complementary spatial information or color features from an image. The method usually is not a stand-alone method to be used to achieve the color from an image accurately [8]. Commonly, the method will work with support from other approaches to ensure the accuracy of the segmentation is achieved. Instead used the stand-alone color histogram method, some of the researchers used the improvised color histogram method such as histogram inter-section, histogram refinement technique or deployed the color histogram method with other approaches such as K-mean algorithm and Convolution Neural Network (CNN).

Execution of the K-Means++ algorithm with the deployment of CIELAB color space to the original image has generated a cluster of six colors [5]. Then, the Inter-Society Color Council-National Bureau of Standards (ISCC-NBS) color terminology is used to identify the color features and locate them on the scene. However, some overlapping objects in the image with a different color have been classified in the same cluster. The impact will lead to inaccurate segmentation when the approach is unable to extract the accurate color features. Meanwhile, when using the histogram and K-Means algorithm, the first pixel from the Region of Interest (ROI) is determined, and the remaining pixels within the ROI are automatically selected to achieve the maximum distance [5]. The approach has produced a better color segmentation result instead of implementing a stand-alone histogram method. However, the approach's initialization process is critical and takes a long time during execution.

Deep learning is a current trend used by researchers in the image processing domain. The ability of Deep Convolution Neural Network (DCNN) to segment and classify ROI areas in medical images has piqued the interest of medical image researchers [7]. The approach involved the convolution and subsampling operation that occurs in its hidden layers. These processes enable the network to learn the network's features, resulting in the automatic extraction of deep features and the effective presentation of the input data. However, in such situations during the training approach, some hidden neurons need to be dropped to avoid underfitting or overfitting situations and keep the balance between variance error and bias error.

On the other hand, to keep the variance error and bias error balance, the Gabor filter and Navier-Stokes algorithms are deployed during the pre-training of the CNN [9]. However, the proposed approach has transformed the image to the grey scale during pre-processing. The drawback to pre-processing is that it eliminates or changes the color feature of the pigment spot, where the color of the spot contains key information, such as the boundary and spatial characteristics of the pigment spot [10].

Based on the comprehensive discussion, it becomes evident that a specific color feature for pigment spots has not been discovered. However, it is noteworthy that color histograms remain one of the most effective methods for analyzing color properties in an image. Moreover, the utilization of the HSV color space in medical images is proven to be more reliable, as it offers a compact, complete, uniform, and natural representation [8]. Taking this into consideration, an exciting opportunity arises to identify the iris pigment spot color feature from an image before segmentation. Through an in-depth exploration of the possibilities offered by the HSV color space and harnessing the capabilities of color histograms, the study can pave the way for accurate and efficient pigment spot detection and analysis in medical imaging.

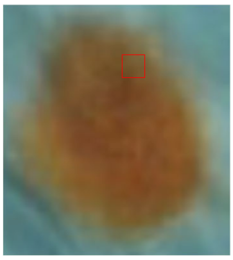
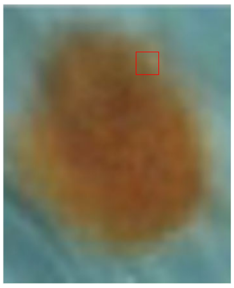
III. Materials and Methods

In advancing this study, the initial step involves an analysis of the pigment spot color properties across the Red, Green, and Blue (RGB), Cyan, Magenta, Yellow, and Black (CMYK), and HSV color spaces. The outcomes of this analysis will establish a pivotal feature for the subsequent pigment spot extraction process. Further comprehensive elucidation of these processes will be expounded upon in the forthcoming sections.

A. *Color Analysis*

Color is the subjective sensation experienced when electromagnetic radiation with wavelengths ranging from 400 nm to 700 nm reaches our eyes [11]. Furthermore, color representation is based on the interaction of colored light and perception [12]. The color of an object only becomes apparent when there is a source of light, which can be either sunlight or generated light with all frequencies within the visible range directed at the object. However, the appearance of color depends on the object's properties. Some light frequencies will be absorbed, while others will be reflected and transmitted by the object. Hence, this study analyzes the color properties of the iris pigment spot to identify reliable features for extraction and segmentation. The color feature analysis, as depicted in Table I, unveils the color properties of the pixels within the pigment spot.

TABLE I. Pigment Spot Color Feature Analysis

Pigment Spot	Color Properties	Pigment Spot	Color Properties
 Original Image  Color Detected	R = 126, H = 31° G = 76, S = 81.7% B = 23, V = 49.4% C = 36% M = 67% Y = 100% K = 33%	 Original Image  Color Detected	R = 132, H = 38° G = 95, S = 75% B = 33, V = 51.8% C = 39% M = 56% Y = 100% K = 26%

Note: Red (R), Green (G), Blue (B), Hue (H), Saturation (S), Value (V), Cyan (C), Magenta (M), Yellow (Y), Black (K).

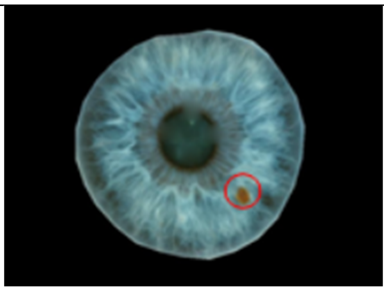
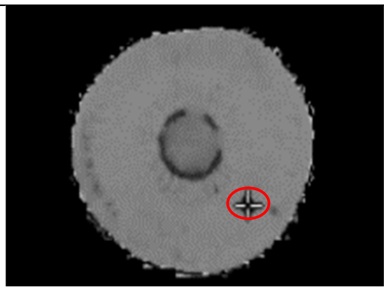
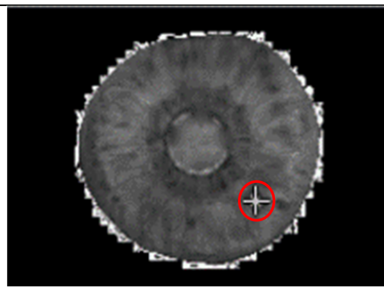
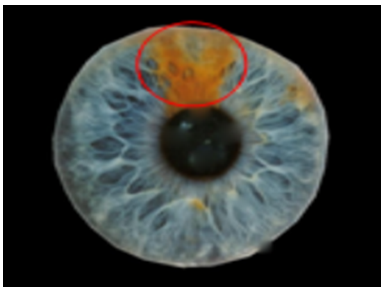
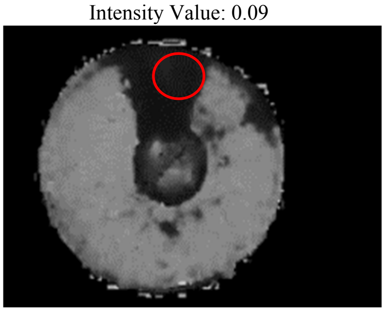
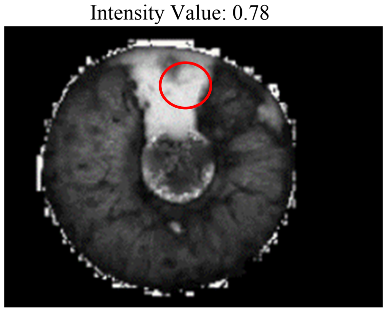
The table presents three color spaces: RGB, CMYK, and HSV. However, despite the original image showing the same spot, different pixels exhibit varying color properties, especially evident in the RGB color space. The RGB values for both spots have a wide range, making them challenging to use as distinctive features. Additionally, the foreground of the spot represents the iris color, which further complicates matters due to the varied combinations of RGB numbers. The situation becomes even more complex when considering the CMYK color space.

Consequently, the HSV color properties appear to be more reliable as a color feature because this color space solely uses the intensity of the properties to define a color feature. Nevertheless, the exact value of intensity for the HSV color properties to be used in feature extraction remains unidentified. On the other hand, an experiment has been conducted to analyze the intensity of the HSV color components. Table II shows the sample of the result.

Based on Table II, the study examined other images in the dataset and observed significant differences in the intensity values between the ROI (in the red circle) and non-ROI areas. This observation led to the conclusion that the intensity value serves as a dependable feature for extracting pigment spot properties. However, the hue component's intensity value was deemed unstable due to its similarity to some non-ROI pixels. As an alternative, the study found the intensity value from the saturation component to be stable, making it a more reliable choice. The ROI was clearly distinguishable from the non-ROI in the saturation component, with the ROI exhibiting higher brightness.

Additionally, through an analysis of the color histogram, the study established that the range of the saturation intensity value was between 0.70 and 0.90. Consequently, all pixels falling within this range were identified as part of the ROI. Given these significant findings from the analysis, the saturation intensity value is considered a valuable and essential feature for color extraction.

TABLE II. ANALYSIS OF HSV COLOR COMPONENT

Original Image	Hue Component	Saturation Component
	 Spot Coordinate: (495, 357) Intensity Value: 0.09	 Spot Coordinate: (495, 357) Intensity Value: 0.78
	 Spot Coordinate: (323,167) Intensity Value: 0.07	 Spot Coordinate: (323, 167) Intensity Value: 0.88

B. Pre-Processing

In the pre-processing phase, image noise is eliminated. During data analysis, it was discovered that the light reflection on the iris image does not provide any helpful information. Consequently, these irrelevant pixels need to be removed to avoid disrupting the subsequent processes. The elimination process starts with converting the RGB image into a grayscale image, as shown in Eq. (1).

$$G_I = 0.2989 \times R_{ch} + 0.5870 \times G_{ch} + 0.1140 \times B_{ch} \quad (1)$$

where, G_I indicate Grayscale image, R_{ch} indicate red color value, G_{ch} indicate green color value, B_{ch} indicate blue color value.

In the subsequent process, G_I is further converted into a binary image B_{ch} to detect the presence of light reflections on the iris surface. The light reflection appears as a white spot on the iris surface. Pixels in B_{ch} with a threshold value greater than 220 are changed to 1, representing the white color and referred to as "holes". Pixels below the threshold value are changed to 0, representing the black color on the B_{ch}. The next step involves dilation, which fills the holes with new pixel values obtained from the nearest neighbor pixels. The next step is to recombine the RGB color components.

C. Feature Extraction

Following the pre-processing stage, the resulting output is utilized in the subsequent step of the method. The following process involved in the extraction is converting from the RGB color model to the HSV color model. The conversion process yields a set of individual images: hue, saturation, and value images. The main objective of this process is two fold—to eliminate irrelevant colors from the image, such as the iris surface color, and to transform the image's color representation from the combination of the RGB color components to the grey scale color component.

In Fig. 1, the saturation component effectively highlights the presence of pigment spots on the iris surface. Subsequently, the process proceeds with a thresholding step to generate binary images for all three components. In this process, the findings from the analysis, precisely the intensity values, are utilized.

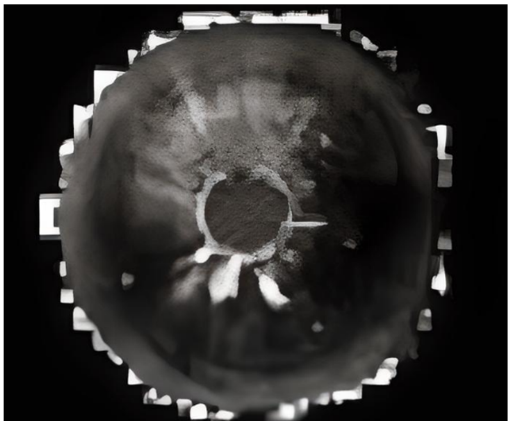


Fig. 1. Saturation image.

The algorithm representing this process is described in Eq. (2). It involves assigning low and high threshold intensity values for each color band. These thresholds are constrained within the range of 0 to 1, with minimum and maximum values defining the extent of influence on the color intensity values.

$$f(x) = \begin{cases} \alpha_k \\ \beta_n^m \\ \gamma_q \end{cases} \quad (2)$$

where, $f(x)$ indicate thresholds image, α indicate hue image, β indicate saturation image, γ indicate value image.

The parameters k, m, n and q, are utilized to capture the maximum intensity values obtained from the analysis, as outlined in Table III. The maximum number of the intensity value has been retrieved from several conducted testing. The testing has start from 0 until 1 for each parameter. As a conclusion, the presented number in Table III is more reliable intensity value to filter out the unnecessary colour on the image.

TABLE III. INTENSITY VALUE

k	m	n	q
0.01	0.90	0.70	0.01

The colour filtering process will executed individually used the Eq. (2) and the process will repeated the intensity value started from 0 until the maximum number for each colour space as presented in the Table III.

Subsequently, the extraction process begins by masking the image to distinguish between the intensity values in the ROI area and the non-ROI area from the saturation image. This step ensures that only the relevant intensity values are selected. The process can be described using the following equations, as shown in Eq. (3) to (5).

$$f\,(A_{\Delta}) = (\,A_i > A_k) \quad (3)$$

$$f\,(\,\beta_{\Delta}\,) = (\,\beta_i \geq \,\beta_n\,) \cap (\,\beta_i \leq \,\beta_m\,) \quad (4)$$

$$f\,(\gamma_{\Delta}) = (\,\gamma_i > \gamma_q) \quad (5)$$

In this context, α represents the hue, β corresponds to the saturation, and γ denotes the value. The mask is represented by Δ, and i represents the image. The resulting output from this process is shown in Fig. 2.

Fig. 2. Feature extraction.

However, the output from the extraction process as shown in Fig. 2 contains irrelevant pixels, which is must be eliminate in order to avoid inaccurate extraction result. The elimination of irrelevant pixels is the subsequent process that enhances the quality of the extraction result. Pixels with a size smaller than 20 will be removed as they are considered irrelevant. Fig. 3 presents the final extraction result after going through the enhancement process.

Fig. 3. Final output feature extraction.

The testing used images from the Miles Research datasets, which can be downloaded freely from their website under "Sample Iris Photos" at http://milesresearch.com [4–6]. The images have dimensions of 1,749 by 1,184 pixels and a resolution of 256 dpi, stored in JPEG format with a 24-bit RGB color model. The total number of images from the dataset is 131 images. The selection of the images was influenced by the existence of the pigment spot. Hence, the 131 images were used through out the study. The extraction result is summarised in Table IV, and the accuracy rate of the extraction process is recorded in Table V.

TABLE IV. TESTING RESULT

Correct Extraction	**Incorrect Extraction**
102 images (77.86%)	29 images (22.14%)

TABLE V. FEATURE EXTRACTION ACCURACY RATE

Detection Rate (DR)	**False Acceptance Rate (FAR)**	**False Rejection Rate (FRR)**
37.1% (49 images)	14.5% (19 images)	48.4% (63 images)

According to Table IV, 77.86% of pigment spot images were successfully extracted from the iris image, showcasing the method's efficacy in pigment spot extraction. Additionally, the result demonstrates the reliability of the intensity value as a valuable color feature for extraction.

Subsequently, the accuracy performance of the method was tested on 102 images that were successfully extracted, and the accuracy rate is presented in Table V. Based on Table V, 53 images were correctly extracted, resulting in a reliable accuracy rate of 51.6%.

While there may be some debate regarding the accuracy rate or the study's results, the most important finding of this study is the reliability of the color intensity from the saturation component as a valuable color feature. Moreover, this feature contains more meaningful and essential information about the image compared to vector features, which may potentially eliminate key information in the image during the process of generation.

IV. RESULT AND DISCUSSION

According to Table IV, 77.86% of pigment spot images were successfully extracted from the iris image, showcasing the method's efficacy in pigment spot extraction. Additionally, the result demonstrates the reliability of the intensity value as a valuable color feature for extraction.

Subsequently, the accuracy performance of the method was tested on 102 images that were successfully extracted, and the accuracy rate is presented in Table V. Based on Table V, 53 images were correctly extracted, resulting in a reliable accuracy rate of 51.6%.

Furthermore, the study had conducted a comparison study towards the accuracy rate between the proposed method with the Colour-based Segmentation approach and Simple Colour Detection by Hue approach. The selection to the methods was influenced by similar scope of the study, which is colour object detection approach. Hence, the comparison was conducted based on the accuracy rate of the approaches to extract the colour from an image. The comparison will used the standard mectric as presented in Table V. The comparison result as shows in Table VI.

TABLE VI. COMPARISON OF FEATURE EXTRACTION ACCURACY RATE

Approaches	Detection Rate (DR)	False Acceptance Rate (FAR)	False Rejection Rate (FRR)
Proposed Method	37.1% (49 images)	14.5% (19 images)	48.4% (63 images)
Color-based Segmentation	28.5% (37 images)	64.8% (85 images)	6.6% (9 images)
Simple Color Detection by Hue	29.3% (38 images)	65.3% (86 images)	5.4% (8 images)

Based on Table VI, the proposed method is the higher detection rate, which is 37.1% equivalent to 49 images compared to other approaches. The improvement gained by the proposed method is +7.8% from to the Simple Colour Detection by Hue approach. In other words, the proposed method is more accurate compare with other approaches in order to extract the pigment spot colour feature. Although the proposed method has generated 48.8% of FRR higher than other approaches, still the proposed method is reliable to be used because the DR of the method is the higher from others.

While there may be some debate regarding the accuracy rate or the study's results, the most important finding of this study is the reliability of the color intensity from the saturation component as a valuable color feature. Moreover, this feature contains more meaningful and essential information about the image compared to vector features, which may potentially eliminate key information in the image during the process of generation.

V. CONCLUSION

As a conclusion, the deployment of the colour histogram and thresholding method n this study is really helpful. However, an improvement is needed to make the method is more reliable to extract the pigment spot feature from iris image. The proposed method begin with deployment of the thresholding method, where the method used to detect the intensity of the spot colour. The improvement occurred when the intensity of the colour based on the HSV colour space is introduced. Later, the colour histogram method is applied to extract the spot colour feature. The extraction was based on the proposed intensity value and slight improvement to the colour selection process as presented in Eq. (3) to (5). Finally the result from the overall processes are the accurate extracted pigment spot from iris image.

The primary goal of this study was to identify the pigment spot color feature, a goal successfully achieved through the analysis of RGB, CYMK, and HSV color spaces. The findings strongly support the use of the color intensity from the saturation component as the most reliable feature for this purpose. To achieve this, the proposed method integrated color histogram and thresholding techniques during the extraction process, enabling successful differentiation between the iris surface and the pigment spot. This study's significant contribution lies in the discovery of the intensity value as a valuable color feature for extracting pigment spots from iris images. Moreover, the implementation of this color feature to extract colored objects from challenging background images is remarkable. Suggestions for future work are highly encouraged, especially concerning accuracy performance enhancement, as discussed in the preceding section. This presents an opportunity to improve the method's accuracy further.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Mohamad Faizal Ab Jabal spearheaded the construction of the research framework and made significant contributions to all experimental processes. Asniyani Nur Haidar Abdullah played a crucial role in setting up the experiments and meticulously crafting the report on research progress. Fallah H. Najjar wrote the final draft of this study. Suhardi Hamid assumed the role of a mentor, proofreader, overseeing the entire progress. Ahmad Khudzairi Khalid contributed innovative ideas and set the initial goals of the study. Finally, Wan Dorishah Wan Abdul Manan focused on conducting an in-depth literature study to provide valuable insights. Together, these collaborative efforts of all authors have culminated in a comprehensive and impactful research endeavor. All authors have approved the final version.

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REFERENCES

[1] A. Helwan, "Deep learning in opthalmology: Iris melanocytic tumors intelligent diagnosis," *medRxiv*, 21263573, 2021.

[2] X. Liu, J. Sun, and X. Wang, "Facial spot contour extraction based on color image processing," in *Proc. the 4th International*

Conference on Biomedical Signal and Image Processing, 2019, pp. 87–92.

[3] H. N. Zugair, Y. A. Alaabedi, F. H. Najjar, and H. H. Razzaq, "Retinal blood vessel segmentation based on the gabor filter and optimized top-hat morphology," in *Proc. AIP Conference Proceedings*, vol. 2977, no. 1, 2023.

[4] D. Srivastava, R. Wadhvani, and M. Gyanchandani, "A review: Color feature extraction methods for content based image retrieval," *International Journal of Computational Engineering & Management*, vol. 18, no. 3, pp. 9–13, 2015.

[5] A. Raza, S. Jost, M. Dubail, and D. Dumortier, "Automatic colour segmentation and colour palette identification of complex images," *Journal of the International Colour Association*, vol. 26, pp. 11–21, 2021.

[6] T. H. Obaida, S. Abd Kadum, F. H. Najjar, and H. M. Al-Jawahry, "Image enhancement using HSV color space, DWT, and BiHE techniques," in *Proc. 2023 6th International Conference on Engineering Technology and its Applications (IICETA)*, 2023, pp. 485–490.

[7] M. Chouksey and R. K. Jha, "A multiverse optimization based colour image segmentation using variational mode decomposition," *Expert Systems with Applications*, vol. 171, 114587, 2021.

[8] U. Erkut, F. Bostancıoğlu, M. Erten, A. M. Özbayoğlu, and E. Solak, "HSV color histogram based image retrieval with background elimination," in *Proc. 2019 1st International Informatics and Software Engineering Conference (UBMYK)*, 2019, pp. 1–5.

[9] D. F. Santos-Bustos, B. M. Nguyen, and H. E. Espitia, "Towards automated eye cancer classification via VGG and ResNet networks using transfer learning," *Engineering Science and Technology, an International Journal*, vol. 35, 101214, 2022.

[10] M. F. Ab Jabal, S. Hamid, N. Z. S. Othman, and M. S. M. Rahim, "Spot Filtering Adaptive Thresholding (SFAT) method for early pigment spot detection on Iris surface," in *Prognostic Models in Healthcare: AI and Statistical Approaches*. Singapore: Springer Nature Singapore, 2022, pp. 347–370.

[11] D. Saleem and M. Nazari-Heris, "Emotional response to different lighting conditions," in *Natural Energy, Lighting, and Ventilation in Sustainable Buildings*, Cham: Springer Nature Switzerland, 2023, pp. 281–300.

[12] X. Zhao, H. Yang, X. Shi, K. Liu, Y. Wang, and G. Zhang, "CPRM: Color perception and representation model for fabric image based on color sensitivity of human visual system," *Textile Research Journal*, vol. 93, pp. 13–14, pp. 2956–2970, 2023.