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Color Correction Technique using an Artificial Color Board and Root-polynomial Color Correction for Smartphone-Based Urinalysis

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Abstract— **Urinalysis is a method that uses urine test strips containing indicators in the form of reagents that will change color when reacting with certain substances in urine that have been determined. Many researchers have developed readings of color change test strips using smartphones due to being portable and easier to use. However, the color information of the obtained image is unstable due to several factors, such as environment light, sensor characteristics, and other stability factors. Color correction was performed to consistently produce color information using the Root-polynomial color correction (RPCC) algorithm based on the color reference standard in Artificial Color Board. The color correction technique was evaluated using images taken with a color temperature variation of 2500 °K – 8500 °K that were recorded using Huawei Nova 5T and Samsung Galaxy A51. The results show that the RPCC method has a good and stable performance on every cellphone used with a color correction evaluation value (ΔE) of 1.8 – 2.6. The results show that the artificial color board and RPCC method can also minimize color temperature so that the color measurement results remain accurate.**

Keywords— ***Color Correction, RPCC, Urinalysis, Smartphone-based***

I. INTRODUCTION

Urine can be used as an indicator of body health. The urine can contain substances that should not come out of the body, such as red blood cells (hematuria), white blood cells, protein, ketones, glucose (glycosuria), and other substances. It occurs when other organs have problems. These substances can be detected using the urinalysis method with the help of a test strip equipped with several reagents. The reagent will change color when it reacts with certain substances that are being determined. This color change will be read to find out how much of the substance is in the urine. Human eyes can notice the color changes. However, it still has a limitation in distinguishing colors. Hence, to aid the reading, a tool is needed, e.g., a urine analyzer.

Along with the times, researchers have developed a reading of the color change of the test strip using a smartphone. The test strip will photograph using a smartphone then the reading results will be processed and displayed on the screen [1]. However, the image obtained is unstable because it is influenced by several factors, such as light and stability factors. Different lighting will produce different image results [2], and it causes color differences in each image and will result in inconsistent readings. The color correction method can carry out so that the colors in the resulting image are consistent and there are no unwanted color differences (the significant color difference is called delta E). Color correction should work well under different lighting [3].

Many color correction methods can be used for correction, which is the mapping method [4]. This method has three algorithms: linear color correction, polynomial color correction, and root-polynomial color correction. Linear color correction (LCC) has the advantage that it does not depend on the lighting used so that LCC can apply to images taken in different lighting. The drawback of LCC is that this algorithm produces a delta E value of more than 10 E (The fair value of delta E is 10 E) [5]. So, the LCC algorithm still considers not suitable for color correction. Another method is to use polynomial color correction (PCC). The results of corrections made by PCC are much better than using LCC. This method uses an expansion on the element vector of the camera response. However, the use of PCC in correction can only perform on images taken at the same exposure. When the lighting used changes, the color value component of each image pixel is multiple by the scalar value of k, which means that each component changes linearly (Sui et al., 2019) [6]. The lighting-dependent characteristics of PCC led researchers to look for ways to remedy these deficiencies. The researchers found a new method that produces a small delta E value and does not depend on the lighting. The technique is a root-polynomial color correction (RPCC), as mentioned in several studies of [6] and [7], which prove that the RPCC algorithm produces a small and consistent delta E value in different lighting. Because of that, we will use RPCC to make a color correction that can reduce color reading error on smartphone-based urinalysis.

II. METHODS

RPCC is an advanced method of PCC that is updated. PCC is a vector expansion method using the n-th degree polynomial of each vector expansion term (ρ). While RPCC uses the polynomial degree as the n-th root so that the k (scale factor) value does not change, different lighting in image capture is no longer a problem. The vector expansion carried out by PCC can be seen in equation (1), and equation (2) is a vector expansion carried out by RPCC

$$\bar{\rho}_{2,3} = \left(r, g, b, r^2, g^2, b^2, rg, gb, rb\right)$$
$$\bar{\rho}_{3,3} = \begin{pmatrix} r, g, b, r^2, g^2, b^2, rg, gb, rb, r^3, b^3, \ldots \\ g^3, rg^2, gb^2, rb^2, gr^2, bg^2, br^2, rgb \end{pmatrix}^T \tag{1}$$

$$\bar{\rho}_{2,3} = \left(r, g, b, \sqrt{rg}, \sqrt{gb}, \sqrt{rb}\right)$$
$$\bar{\rho}_{3,3} = \begin{pmatrix} r, g, b, \sqrt{rg}, \sqrt{gb}, \sqrt{rb}, \sqrt[3]{r}, \sqrt[3]{b}, \sqrt[3]{g}, \\ \sqrt[3]{rg^2}, \sqrt[3]{gb^2}, \sqrt[3]{rb^2}, \sqrt[3]{gr^2}, \sqrt[3]{bg^2}, \sqrt[3]{br^2}, \sqrt[3]{rgb} \end{pmatrix}^T \tag{2}$$

The resulting vector expansion (ρ) is an N × i matrix where N is the response value of the expanded camera with the number of polynomials as much as i. Then the result of the expansion is multiplied by the color correction transformation matrix (M) to produce a new color correction matrix (q) which written as:

$$q = \rho M \tag{3}$$

Matrix M is obtained from:

$$M = \left(\rho^T \rho\right)^{-1} \rho^T Q \tag{4}$$

where Q is an N × 3 matrices of the color reference value used.

This study uses an artificial color board as the color reference value, containing 24 different colors whose R, G, B values are taken based on the colors found on the X-Rite ColorChecker Passport. X-Rite ColorChecker Passport is a color board that complies with international standards and is widely used in camera calibration and color correction [8]. The colors are sorted according to the order of the X-rite colors with slight modifications. In the center of the board, a special place is made to put the test strips so that the colors are divided into two parts on the right and left and then printed on a white acrylic board measuring 14 × 7cm. The board is also given an additional circle at each end to facilitate the segmentation process. The shape of the color board design refers to the research conducted by the researcher Anthimopoulos [9]. We can see the artificial color board in Fig.1 dan X-rite ColorChecker passport in Fig.2.

Fig. 1. The artificial color board

Fig. 2. The x-rite color checker passport standard

Before we use the artificial color board in the experiment, a trial is carried out first by comparing the color correction results on the X-rite ColorChecker image with the color correction results on the created color board image. The value that we use to compare is the size of the color difference between the color reference and the color from a captured image. The color difference is called delta E (ΔE), and the smaller the delta E you get, the more similar the color from the captured image and the color reference. We use the CIE1976(L*a*b*) [10] method to calculate delta E. Before we can calculate delta E, we must convert RGB color space to LAB color space as instrumental space [11]. The equation for the method is:

$$\Delta E^* = \sqrt{\left(L^*\right)^2 + \left(A^*\right)^2 + \left(B^*\right)^2} \tag{5}$$

ΔL, Δa, and Δb are the size of the color difference before and after correction in terms of three different channels. Suppose the Delta E results produced by the artificial color board do not differ much from the x-rite. In that case, the synthetic color board used follows the Color Checker standard.

In these experiments, we use two different smartphones that are in the same class to take pictures.

TABLE I.
SAMSUNG AND HUAWEI CAMERA SPECIFICATIONS COMPARISON

Smartphone	**Camera**
Huawei Nova 5T	- 8 MP, f/1.8, 28mm (wide), 1/2.0", 0.8µm, PDAF - 16 MP, f/2.2, 13mm (ultrawide), 1/3.1" - 2 MP, f/2.4, (macro) - 2 MP, f/2.4, (depth) -AI *Ultra Clarity*
Samsung A51	- 48 MP, f/2.0, 26mm (wide), 1/2.0", 0.8µm, PDAF - 12 MP, f/2.2, 123˚ (ultrawide) - 5 MP, f/2.4, (macro) - 5 MP, f/2.2, (depth)

Fig. 3. Experimental setup to capture test strip with color temperature variation

The smartphones are Huawei Nova 5T and Samsung A51, which have similar camera specifications. We can see a comparison of the specifications of the two phones in Table 1. Objects were taken using the OpenCamera application, which is open source with the selection of Standard Mode (STD) as the mode used. This mode is the normal mode in the OpenCamera application to take a single picture. The white balance is off, and focuses settings are automatically, and the camera used is a 12 MP camera for both mobile phones. The image is taken in a dark room without ambient light, using a stationary pole to support the phone and a lamp. The experimental setup can be seen in Fig.3. The light source used in this research is YPP YY 150 LED lamp that can be varied in color temperature from 2500 °K – 8500 °K . Image retrieval is done with a distance of 11 cm from the object because that distance is the distance that best suits the desired image results.

The object was captured by varying the color temperature from 2500 °K – 8500 °K with 500 °K intervals for each increase. It is to prove whether the color correction algorithm used works under the influence of the lamp's color temperature or not. The difference in color temperature in the lamp will produce a different light color, affecting the resulting image. The smaller the color temperature, the more yellow the resulting color will be, while the higher the color temperature used, the more bluish the image.

The object image was taken by using a smartphone then transferred to a computer for color correction. The image will be filtered first using a gaussian filter to reduce noise in the image [12]. After that, the image will be segmented using the template matching method to retrieve the required ROI with the help of image masking [13]. The circle on the color board will be detected and used as a reference point to crop the image into smaller ones to match the size of the masking image used. After that, the ROI of the color board image and the test strip image were taken separately by applying the masking image to the color board image, as shown in Fig.4. The color value in the ROI will be used as the input for color correction. Then the image will go through the color correction training stage, which has been initialized first, then color correction is applied to the image.

The first initialization is to select a color correction model. The intended color correction model is a color mapping method for correction. In this study, the method used is a root-polynomial color correction (RPCC). After that, choose the value of D65 as the illumination used. This illumination selection helps convert the sRGB color space to the CIEXYZ and CIE L*a*b because the conversion process requires a standard white point value corresponding to the selected illumination. The next step is the selection of the XYZ reference color space. There are two choices of the XYZ reference color space, namely CIEXYZ 1931 and 1964. The difference between the two-color spaces is the perception of the color space to the way the eye sees colors and the range of color values. The selection of the XYZ color space is important because it is necessary to convert the color space. Different choices of the XYZ color space will have different conversion results.

The next stage is whether the scale function is turned on. When the scale function is turned on, the training process will carry out the method of calculating the optimal scale value. The scale value is used to correct the darkness of the image. In this study, the scale function is turned on. The process of calculating the optimal scale value (k) can be seen in Fig.5. Next is to check whether the white balance function is turned on. If it is turned on, the color correction method using white balance will work. The last initialization is checking the value bias function. When turned on, the bias will add a value of '1' to the previous column of the correction matrix. The discrimination process is the same as the scale function, which is to correct the darkness of the image. However, this bias function only works on images taken with a fixed exposure. After the initialization process, the training process gets the optimal matrix value (M) and optimal scale (k). The optimal matrix value (M) is obtained using equation (4). The process of calculating the optimal matrix (M) can be seen in Fig.6.

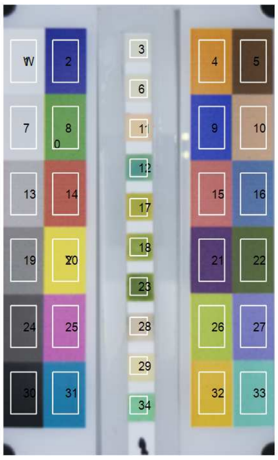


Fig. 4. Segmentation of artificial color board and test strip

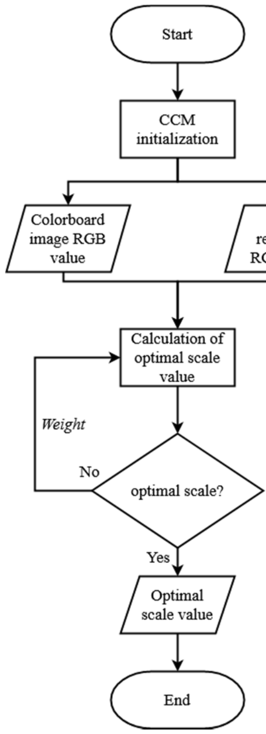


Fig. 5. Flowchart diagram of optimal scale value computation

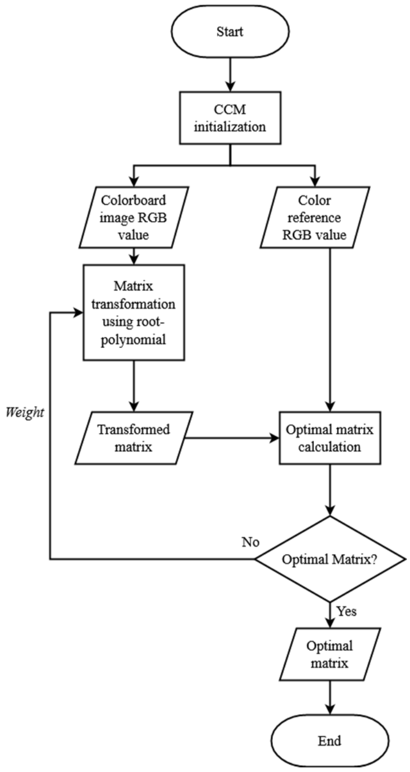


Fig. 6. Flowchart diagram of optimal matrix computation

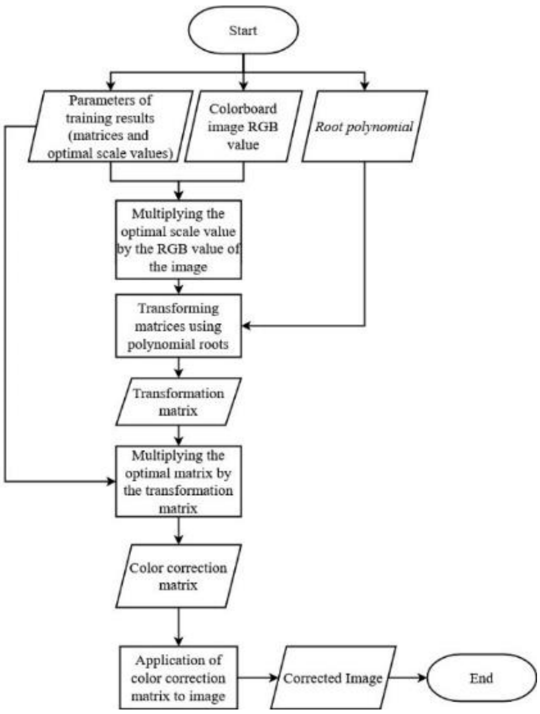


Fig. 7. Flowchart diagram of color correction method

After the correction training process is complete, the results obtained from the training and correction models are used as input data for the color correction application process. The flow of the color correction application process on the test strip image can be seen in Fig.7. The first step is to multiply the optimal scale value by the RGB value of the test strip image. The multiplication result is a vector matrix transformed using the RPCC method using equation (2.7) and produces a transformation matrix. The matrix is then multiplied by the optimal matrix obtained during the training to create a color correction matrix. This matrix will be applied to correct the image and produce a color-corrected image. The equation used in the color correction application process can be seen in equation 3.

III. RESULT AND DISCUSSION

A. Artificial Color Board Comparison with X-rite ColorChecker Passport

The artificial color board and x-rite Color Checker passport were captured under a light source with a standard color temperature of 6500 °K. The image is segmented by the template matching method to obtain the required ROI. The ROI obtained was 24 ROI from each color on the color board with 96 × 60 pixels. The color correction method used is matrix multiplication using the second-order RPCC algorithm.

The results of color correction applied to the Color Checker produce a delta E value of 1.5 E for image capture with Huawei phones and 1.9 E for image capture with Samsung phones. Meanwhile, the results of the color correction applied to the color board produced a delta E value of 1.8 E for image capture with Huawei phones and 2.4 E for image capture with Samsung phones. The color difference results from the correction of the color board used are more significant than the ColorChecker.

However, the difference between the two is not very significant, which can be seen from the two and is still in the range of values considered good ($\Delta \leq 10$ E). The use of color correction using an artificial color board can replace the x-rite ColorChecker as a color board in helping the color correction process. In addition, the use of color values used in the manufacture of color boards is by the x-rite color checker color values listed on the website. The comparison of the results of the two corrections can be seen in Table 2.

B. Color Correction Results in Different Color Temperature

Image retrieval at each color temperature change was carried out nine times and produced 234 images, with each cell phone producing 117 images. The variations in color temperature in the light source affected the image results. This color temperature variation also affects the color shift, resulting in the color not matching the original and producing an enormous delta E value. At a 2500 °K – 4000 °K color temperature, it gives a yellow impression to the image and affects bright colors such as white and yellow. While at a

TABLE II.
DELTA E AVERAGE VALUE ON COLORBOARD AND X-RITE COLORCHECKER

Smartphone	**Object**	**Delta E**	
		Original	**Correction**
Huawei	Color Board	4,5	1,8
	X-Rite	5,2	1,5
Samsung	Color Board	5,2	2,4
	X-Rite	8,5	1,9

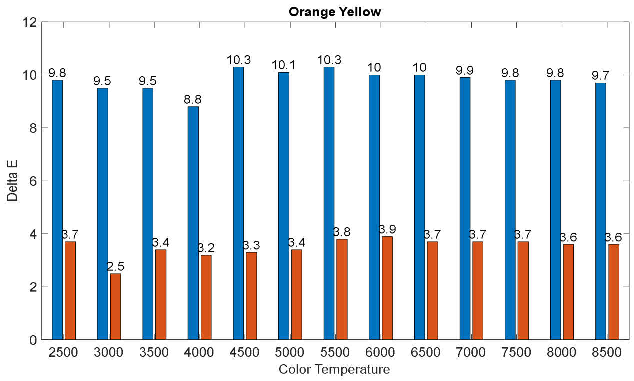


Fig. 8. Delta E value of the yellowish-orange color from the original and corrected image captured with Samsung A51

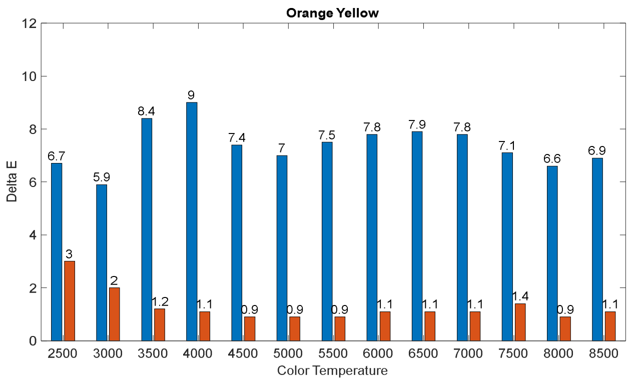


Fig. 9. Delta E value of the yellowish-orange color from the original and corrected image captured with Huawei Nova 5T

color temperature of 7000 °K – 8500 °K, which offers a blue appearance on the image. If we look at the correction results for each color, several correction delta E results are more significant than the delta E value before correction, such as white.

However, some colors are successfully corrected by color correction, such as yellowish-orange. It can occur due to the scale value from the training correction results applied to the image because the function of the scale value is to correct the overall brightness level of the image, so the correction results do not always apply to every color. If the scale correction results in a lighter image, it can affect dark colors. The opposite also applies. However, it cannot be tolerated because the value of delta E produced by each color is still within the allowable value range and stable. The difference between the results of delta E from the original image and the correction for yellowish-orange can be seen in Fig.8 and Fig.9. From the experiments, the result of a 4500 °K – 7500 °K color temperature has the same value of delta E of each color patch, referencing the best color temperature range used as a light source in image capture.

Fig.10 and Fig.11 display a comparison graph of the original and corrected color on an image taken at 6500 °K to represent the results in the color range of 4500 °K – 7500 °K. Color correction also proved to work well on both phones. It can be seen from the average value of the resulting delta E still <10 ΔE, which indicates that the color of the corrected image with the reference value or the original value tends to be similar, and the difference can only be distinguished with the help of tools.

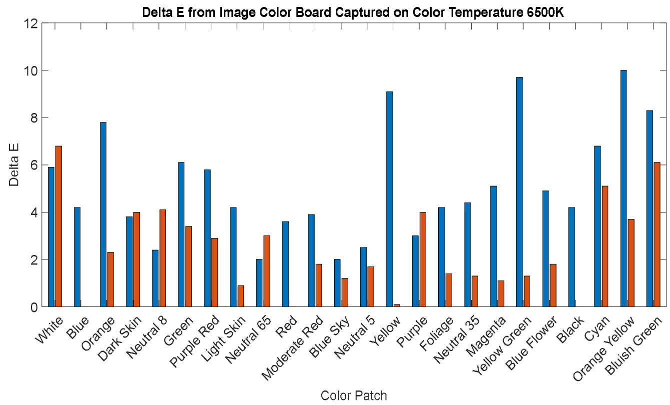


Fig. 10 Delta E from Image Color Board Captured on Color Temperature 6500 °K (Samsung A51)

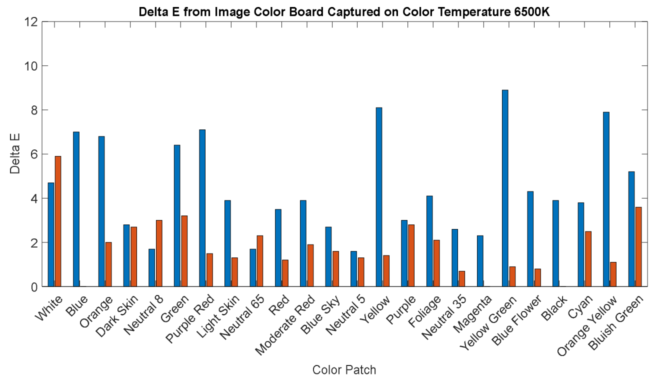
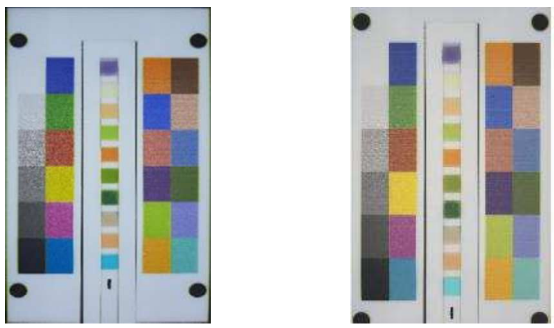


Fig. 11. Delta E from Image Color Board Captured on Color Temperature 6500 °K (Huawei Nova)



(a) (b)

Fig. 12. (a) Original image captured with Samsung A51 (b) Corrected image.

(a) (b)

Fig. 13. (a) Original image captured with Huawei Nova (b) Corrected image.

The application of color correction on the image can be seen in Fig.12 and Fig.13. The image was captured at a color temperature 6500 °K. From the picture, we can see that the color correction can reduce the bluish color and the high exposure from the image and make the color more natural.

IV. Conclusions

The artificial color board used in this study has been tested to comply with the standard and can be used as an alternative to the x-rite color checker. The artificial color board can also reduce the effect of color temperature so that the color measurement results remain accurate. RPCC works well on both phones and is not affected by variations in color temperature when taking images. The results show that the color correction values in images taken with different color temperatures produce values that tend to be stable with insignificant differences in values. The use of the best color temperature range is at a value of 4500 °K – 7500 °K because it has the same correction value and can be used to reference the best color temperature range that can be used as a light source in image capture. The artificial color board and color correction method can be used in smartphone-based urine test strip readings.

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