Strip Test Analysis Using Image Processing for Diagnosing Diabetes and Kidney Stone Based on Smartphone

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***Abstract* — Urine is a useless substance that produced by the body metabolism that needs to be excreted. Many research about urinalysis shows that the excreted urine can be an indicator of someone's health condition by the composition of urine itself. One of the methods used to know about urine composition is by using strip test. Strip test works similarly with litmus paper, when the surface of the paper is making a contact with the substance, the color of the reagent will change. Strip test can show the user about the substance that should not be excreted alongside the urine, for example glucose, blood, nitrite, ketones, bilirubin, and urobilinogen. The problem of using a strip test is that without any strip test analyzer device (semi-reflective photometer), some people will have difficulties interpreting the result with the reference table [1]. This system is created to help to interpret the strip test result using image processing by capturing the strip picture using a smartphone. The system can determine the discoloration of the strip with more details and could give a result whether the patient is possibly diabetes or not and detect the possibilities of kidney stone. From the results of the experiments conducted, the system is able to classify the result with 93.4 % accuracy for blood classification (to identify the kidney stone) and 90% accuracy for glucose classification (to identify diabetes). It can be concluded that the system can be used to carry out strip test without any help of semi-reflective photometer or medical expert.**

Keyword: Urinalysis, Strip Test, Image Processing

I. INTRODUCTION

Point-of-care testing (POCT) is a medical diagnostic testing at or near the point of care [2]. The purpose of POCT is to help the medical experts carried out the test without bringing the specimens to the laboratory and waiting for a long time to receive the result in which the care must be continued without knowing the patient condition. POCT can be done anywhere that didn't have any access to laboratories. In some cases, the strip test is not able to meet the expectation of the POCT because of complication while reading the strip.

For example, various strip test has been developed for decades yet the device to help the medical expert reads the result is not yet available and widespread. Until today, the device is still being developed to make the strip test become easier. Urine strip test is a basic diagnostic tool used to determine the pathological change in the urine. A standard urine test strip may contain up to 10 different reagents (chemical pad) which react to a specific substance. The analysis includes testing for glucose, blood, nitrite, ketones, bilirubin, and urobilinogen. There are two kinds of strips the serve for different purposes, such as qualitative strip which determine a negative or positive result, and the semi-quantitative strip which give an estimation of the quantitative result. This type of analysis is commonly used to monitor and control the diabetic patient [3].

While there is a similar system built on a smartphone to identify the discoloration of strip test [1], our system is able to diagnose the result of the strip test and give a suggestion for the user to take further action. Furthermore, our system is able to acquire the value of blood and glucose reagent that is used by the medical experts to give a diagnosis for the patient.

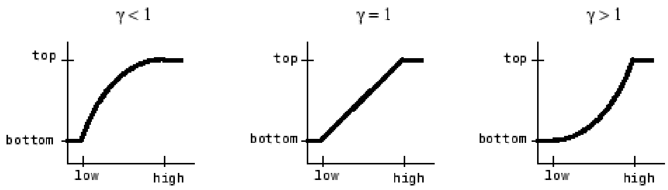
II. THEORY

A. Gamma Correction

Gamma Correction, or often called gamma, is a non-linear operation used to encode and decode the luminance values in image. Gamma correction is defined by following equation:

$$V_{out} = AV_{in}^{\gamma} \qquad (1)$$

Where the non-negative real input value is V_{in} raised to the power γ and multiplied by the constant A, to get the output value V_{out}. In the common case of $A = 1$, inputs and outputs are typically in the range 0–1. If the gamma value $\gamma < 1$ is called encoding gamma, while $\gamma > 1$ is called decoding gamma.



(a) (b) (c)

Figure 1. Gamma Non-Linear Function (a) encoding gamma (b) normal gamma (c) decoding gamma

Fig. 1 shows the function of a matrix when affected by gamma correction. Figure 1.a shows the function of the encoding gamma with the gamma value greater than 1. Figure 1.c shows the decoding gamma with gamma value less than 1. While figure 1.b shows the original image without any gamma effect.

B. HSI Color Space

The HSI color space is very important and attractive color model for image processing applications because it represents color s similarly how the human eye senses colors. The HSI color model represents every color with three components: hue (H), saturation (S), and intensity (I). Fig. 2 illustrates how the HSI color space represents colors.

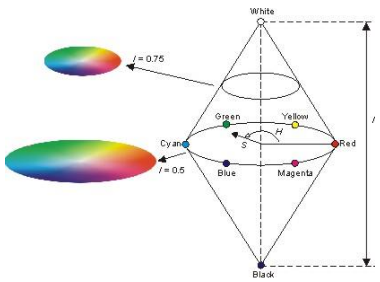


Figure 2. HSI Color Space

From the Figure 2, the Hue component describes the color itself in the form of an angle between [0,360] degrees. The color is divided in specific degree, 0 degree mean red, 120 means green 240 means blue. 60 degrees is yellow, 300 degrees is magenta. The Saturation component signals how much the color is polluted with white color. The range of the S component is [0,1]. The Intensity range is between [0,1] and 0 means black while 1 means white. The following formula is used to calculate HIS color space from the RGB color space.

$$H = \begin{cases} \theta & B \leq G \\ 360 - \theta & B > G \end{cases}$$

$$H = \cos^{-1}\left\{\frac{\frac{1}{2}[(R-G)+(R-B]}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right\} \tag{2}$$

Hue is the degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, blue, and yellow. It has degree value from 0 to 359 represented as H in figure 2. Hue starts from red (H=0) to green (H=120), to blue (H=240), then back to red.

$$S = 1 - \frac{3}{(R+G+B)} * \min(R, G, B) \tag{3}$$

Saturation is the value that represents the distance of the color from center of the circle in figure 2. Hue will become more meaningful when the saturation value is approaching 1 and will be less meaningful when the saturation value approaches 0.

$$I = \frac{1}{3}(R + G + B) \tag{4}$$

Intensity represents the amount of white present in the color. Higher intensity means more white color present in the color. On the other hand, lower value of intensity means more black color present in the image.

C. Fuzzy for Decision Making

Fuzzy is a form of many valued logic that vary between zero to one. The purpose of fuzzy is to handle the concept of partial truth. Unlike Booleans, the truth value of variables may only be zero or one. By using fuzzy, the truth value of variables may vary from zero to one, from completely false to completely true. For example, when some group of people were asked about the weather, some say it is cold, some will say it is warm and so on. The fuzzy logic is capable of giving an acceptable reasoning from many different truth value of variables.

The input of a system is translated into a crisp which may hold different categories of input. The following figure is an example of crisp for temperature sensor used by an air conditioner.

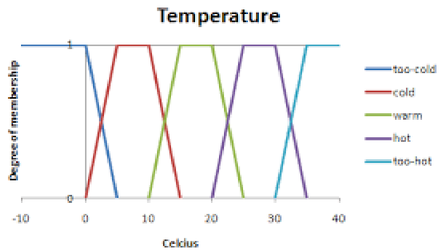


Figure 3. Membership function

Figure 3 shows the temperature membership function which divided into five categories. Ranging from too cold, cold, warm, and so on. The next step is using logic operators to create a decision output. The following table is an example of logic operator.

Table 1. Logic operator

Boolean	Fuzzy
AND(x,y)	MIN(x,y)
OR(x,y)	MAX(x,y)
NOT(x)	1 – x

Table 1 shows the available logic operator that could be used in determining the value between 2 membership function. The "and" operator in membership function is used to find the smallest value between 2 membership function while the "or" operator is used to determine the biggest value between 2 membership function.

III. DESIGN SYSTEM

System design explain the process of the system from input of strip test, the image processing, and finally classifying the result of strip test in the following diagram.

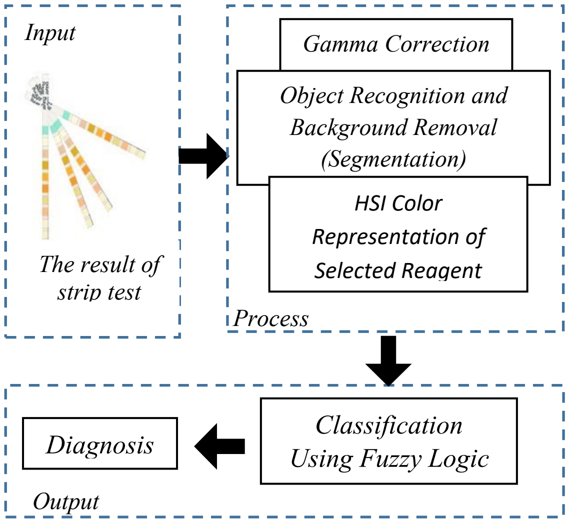


Figure 4. Diagram System

Figure 4 illustrates the system design block which divided into three steps, input, process, and output. While there is a previous research with similar system built on a smartphone to identify the discoloration of strip test [1], our system is able to diagnose the result of the strip test and give a suggestion for the user to take further action. Each step will be explained in the following paragraph.

A. Input

The input of the system is a strip that has been used for the test. Using the smartphone camera, patient may capture the strip image and the system will start processing the captured image. The following picture is User Interface for the patient.

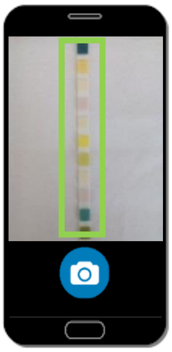


Figure 5. Application User Interface

The captured image of the strip should include all of the reagents in the strip, otherwise the system can't identify the glucose and blood reagent. The green area is provided to help patient guide the camera and capturing the image correctly.

B. Image Correction

The image correction can be done according to the luminance of the room the strip was captured in using gamma correction. The value of gamma may vary in accordance with the luminance read by the smartphone sensor. By capturing an image with pre-determined RGB color, we can determine how much gamma that needs to be applied for varying light intensity. The following table is an example of gamma correction.

Table 2. Gamma correction

Intensity	Image	Gamma (γ)	R	G	B	Color (RGB)
10 – 20 lux		-	136	120	2	230, 220, 100
		1.1	140	122	5	
		1.2	148	130	7	
		1.3	162	145	13	
		1.4	186	165	26	
		1.5	199	187	50	
		1.6	216	207	86	
		1.7	230	224	129	
90 – 100 lux		-	142	114	14	230, 220, 100
		1.1	152	123	21	
		1.2	159	131	26	
		1.3	172	146	38	
		1.4	188	166	59	
		1.5	205	188	90	
		1.6	220	208	127	
		1.7	233	225	165	

Table 2 shows the result of gamma correction. The experiment is carried out in a different lighting condition. The first experiment is carried out with 10 – 20 lux light intensity. The result shows that the optimum value for the gamma is 1.7 because the RGB value of the image is close with the actual RGB value. The next experiment is carried out with 90 – 100 lux light intensity and the result shows that the result of $\gamma = 1.6$ is the closest to the real RGB value of the image.

C. Object Recognition and Background Removal

The purpose of the Object Recognition is to locate the pixel of the strip. The Object Recognition method will find the starting point and the ending point of the strip image. The next step after determining the starting point and the ending point of the strip image is removing the background. This step purpose is to remove unnecessary pixel outside the strip image. The figure bellow shows the result of the Object Recognition and the Background Removal method.

(a) (b)

Figure 6. (a) Preprocessed image (b) Removed background

Figure 6.b shows the result of background removal process. The length and width of strip picture will be used to determine the position of blood and glucose reagent. From up to down, the blood reagent is placed on the second pad, while the glucose reagent is placed on the sixth pad. Because of width and the length of each reagent is the same, we can

assume the width of strip image is the same as the width and length of the reagent.

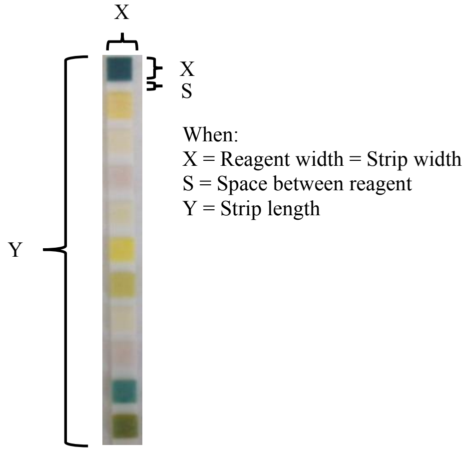


Figure 7. Illustration of Strip

With known variable in the above figure 7, we can determine the Y Cartesian position of glucose and blood reagent using the following equation.

$$S = \frac{Y - 5*X}{11} \tag{5}$$

$$Y_{blood} = X + S \tag{6}$$

$$Y_{glucose} = 5*(X + S) \tag{7}$$

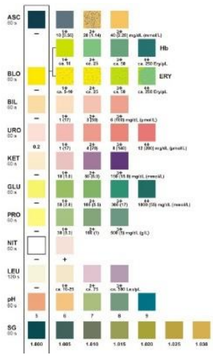
From the equation 6 and 7, we acquire the starting coordinate of the blood and glucose reagent. The blood reagent starts at pixel (0, Y_{blood}) and ends at (X, Y_{blood}). While the glucose reagent starts at (0, $Y_{glucose}$) and ends at (X, $Y_{glucose}$). The acquired coordinate will be used to segmenting the reagents. The following figure is the result of reagent segmentation.

Figure 8. Results of Reagent Segmentation

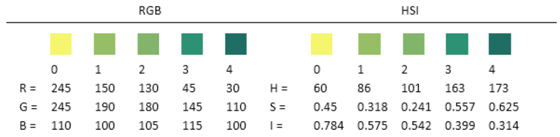
Figure 8 shows the result of reagent segmentation. The RGB value of the acquired glucose and blood reagent will be converted into HSI color representation for the feature extraction.

D. HSI Color Space

Using the equation 2 through 4, we can calculate the HSI value of each reagent. Each pixel of each reagent will be converted into the HSI color space. After that, the mean value of each reagent will be calculated and it will be used as input for the classification. The following figure is the result of HSI conversion of the strip reference table

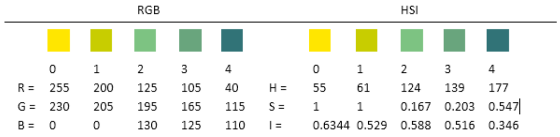


(a)



RGB	0	1	2	3	4	HSI	0	1	2	3	4
R =	245	150	130	45	30	H =	60	86	101	163	173
G =	245	190	180	145	110	S =	0.45	0.318	0.241	0.557	0.625
B =	110	100	105	115	100	I =	0.784	0.575	0.542	0.399	0.314

(b)



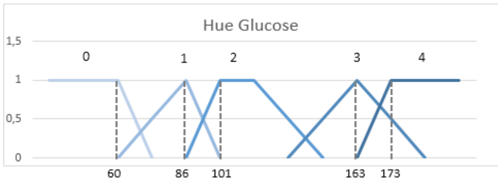
RGB	0	1	2	3	4	HSI	0	1	2	3	4
R =	255	200	125	105	40	H =	55	61	124	139	177
G =	230	205	195	165	115	S =	1	1	0.167	0.203	0.547
B =	0	0	130	125	110	I =	0.6344	0.529	0.588	0.516	0.346

(c)

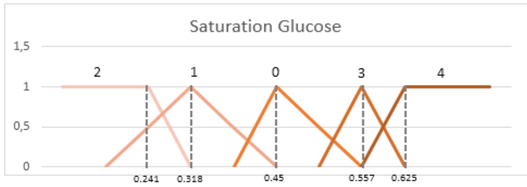
Figure 9. (a) Strip reference table (b) Glucose color reference (c) Blood color reference

E. Classification

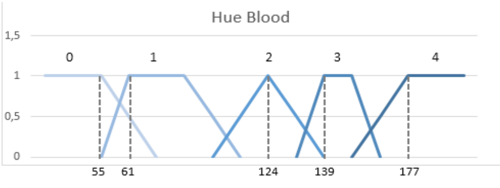
For classification purpose, the system need 2 input parameter, Hue and Saturation, to determine the result of the strip. The membership function used for the classification is generated from the reference table (figure 8). Figure 9 illustrates the membership function of blood and glucose reagent.



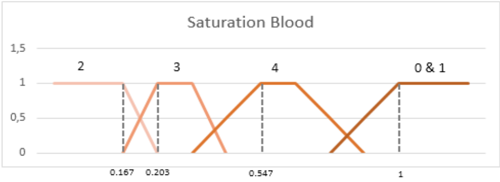
(a).I



(a).II



(b).I



(b).II

Figure 10. (a) Membership function of glucose reagent (b) Membership function of blood reagent

Figure 10 shows the membership function used as input for the classification. Figure 10.a.I is a membership function used to determine the classification of hue glucose reagent. While Figure 10.a.II is a membership function for the glucose saturation value. The Figure 10.b.I and II are membership function of hue and saturation of blood reagent. From the figure 9.a shows that the range of HSI value between each category is fluctuating. While the difference of HSI value between 1 and 2 is very small, there is very large gap between 2 and 3 thus making the membership function took shape of trapezoidal. These large gap of hue and saturation value makes the membership function become sloping while the small gap makes the membership function become steep.

The following step would be determining the result by using a specific rule set. By using OR logic operator, the maximum truth value will be selected to be used as a parameter for the rule set. Each reagent will have their own rule set. Figure 10 show the rule set of blood and glucose reagent.

Table 3. (a) Glucose rule set (b) Blood rule set

Hue \ Sat	0	1	2	3	4
2	1	2	2	3	3
1	0	1	1	2	3
0	0	1	1	2	3
3	1	2	3	3	4
4	2	2	3	4	4

(a)

Hue \ Sat	0	1	2	3	4
2	2	1	2	3	4
3	2	2	3	3	4
4	3	3	4	4	4
0 & 1	0	1	1	2	2

(b)

After receiving the classification result, the system will compare the result with the reference table via database. From the reference table, we acquire the semi-quantitative result of blood reagent as follows, if the result is 1 then the blood contained in the urine is 10 Erythrocytes/µL, if the result is 2 then the blood contained is 25 Erythrocytes/ µL, and so on. Any slight existence of blood in urine means that there is a mechanical trauma caused by injuries, kidney stones, or ingestion [4].

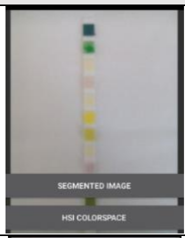
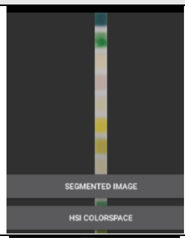
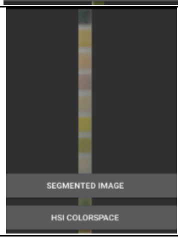
The reference table of glucose is as follows, if the result is one then the amount of glucose contained is 50 mg/dL, if the result is 2 then the amount of glucose is 100 mg/dL, and so on. While normally the glomeruli can filter up to 160 to 190 mg/dL of glucose, if the amount of glucose is lower than that, then the kidney can completely absorb the glucose. On the contrary, if the amount of glucose exceed the normal threshold, the glucose will be excreted with the urine. While the most common cause of glycosuria is diabetes, many conditions may decrease the glomeruli threshold, causing increased glucose in the urine [4].

IV. EXPERIMNTAL RESULT AND ANALYSIS

The table shown below is a sample of the analyzed result from the system. Each table will represent the method used in this research, Background removal, Segmentation of reagent, HSI conversion, and Classification result.

1) Background Removal

Table 4. Image of strip test

INPUT	OUTPUT
	
	

From the table 4 we acquire that the system is able to do background removal using the purposed method. Out of 30 experiments carried out, the system is able to remove the unnecessary background while still preserving the strip image. The strip image will be segmented into 10 reagents to extract the feature of glucose and blood reagent.

2) *Segmentation*

Table 5. Reagent Segmentation

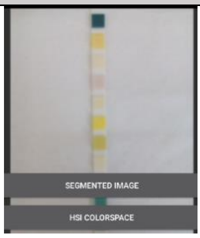
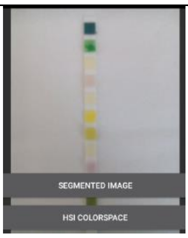
<table>
<tr><th>Input image</th><th>Segmented reagent</th></tr>
<tr><td rowspan="2">
</td><td>
blood</td></tr>
<tr><td>
glucose</td></tr>
<tr><td rowspan="2">
</td><td>
blood</td></tr>
<tr><td>
glucose</td></tr>
</table>

Table 5 shows the result of glucose and blood segmentation. Using equation 5, 6, 7 and previously acquired height and width of the strip, the system is able to determine the position of each reagent and selecting the glucose and blood reagent in the second and sixth pads of the strip. Out of 30 experiment carried out, the system is able to segment the reagent even though there is some unnecessary part of strip included in the result. The unnecessary part will not be counted for the mean of HSI for each reagent.

3) *Classification*

Table 5. Classification comparison

No.	System Classification Result		Laboratories Reading		Error	
	Glucose	Blood	Glucose	Blood	Glucose	Blood
1.	0	0	0	0	T	T
2.	0	1	0	1	T	T
3.	0	1	0	1	T	T
4.	0	3	0	3	T	T
5.	0	0	0	0	T	T
6.	0	0	1	0	F	T
7.	2	0	2	0	T	T
8.	0	0	0	0	T	T
9.	0	0	0	0	T	T
10.	0	0	0	0	T	T
11.	0	4	0	4	T	T
12.	0	0	0	0	T	T
13.	0	1	0	1	T	T
14.	0	0	0	0	T	T
15.	2	0	2	0	T	T
16.	0	0	0	0	T	T
17.	0	0	0	0	T	T
18.	0	0	0	0	T	T
19.	2	0	2	0	T	T
20.	3	0	3	0	T	T
21.	0	0	0	0	T	T
22.	0	0	0	0	T	T
23.	0	0	0	0	T	T
24.	3	0	2	0	F	T
25.	0	0	0	0	T	T
26.	0	0	0	0	T	T
27.	0	1	0	2	T	F
28.	4	0	3	0	F	T
29.	0	0	0	2	T	F
30.	0	0	0	0	T	T
	∑error				3	2
	Error Percentage(∑error/∑data * 100)				90%	93.4%

Table 5 shows the result of classification using fuzzy logic. Out of 30 experiments carried out, there are 5 errors which 2 of it is error in reading the blood reagent and 3 of it is error in reading the glucose reagent. This mistake may be caused by a very low lighting condition when capturing the strip, this causes the HSI value of the reagent is deviating further from the true value of the strip and the classification result is different from the laboratories reading.

4) *Diagnosis*

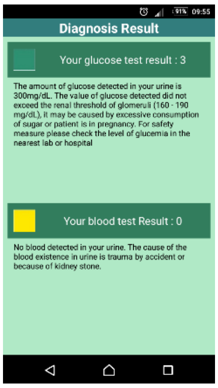


Figure 11. Diagnosis Result

Figure 11 shows the result of diagnosis according to classification result. When the result of glucose classification is less than or equal with 2, it means that there is a possible decrease of renal threshold value of glomeruli or the patient is consuming excessive amount of glucose. While the result is higher than 2 it may be caused by hyper glaucoma condition. For the blood diagnosis, any slight existence of blood alongside the urine means that the kidney is suffering from trauma caused by accident or kidney stone.

V. CONCLUSION

Based on all the results, the application is able to identify the discoloration of the strip. The experiment carried shows that the system can recognize the strip, segmenting the reagent, and classifying the result according to the reference table with 93.4 % accuracy for blood classification and 90% accuracy for glucose classification. By using this application, the user may carry out the strip test by themselves without the help of semi-reflective photometer machine or medical expert. For the future works, the researchers will expand the recognition process into the other reagents and providing multiple databases for different kind of strips to make the system more convenience and ergonomics for the user.

VI. REFERENCE

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