Interpretation of Urine Dipstick Results Based On Color Similarity Using Linear Interpolation Curve Fitting

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***Abstract*— Automation of urine dipstick reagent results interpretation is influenced by color space selection and the method to determine color similarity between a tested color and the target color chart. Color similarity among colors can be evaluated by calculating their Euclidean distance in a color space; however it only calculates the distances between a tested color and a series of target color in a color chart, producing a stepwise quantification. It is not suitable if a value between two target colors should be estimated, producing a smoother quantification.**

This research enhances the method for urine dipstick color interpretation. A stepwise linear interpolation algorithm in CIELAB color space is used. It produces smoother quantification and a possibility to verify whether the tested reagent is belong to the certain color chart or not. A formula resulted from our algorithm can be easily implemented for interpreting the score of the tested reagent. The result of this automation method is evaluated by comparing the result with a visual interpretation and color interpretation by using Euclidean distance only. The result shows a promising method in an automation process for dipstick urinalysis.

***Keywords*— Linear Interpolation Curve Fitting, Color Space, Urinalysis, Color Similarity**

I. INTRODUCTION

Dipstick urinalysis is a diagnostic method for determining chemical composition in patient urine. This analysis is commonly used by diabetic patients for controlling and maintaining their health, or by medical laboratories. A currently available dipstick may comprise of several reagent strips. Besides its ability to determine the level of glucose for diabetic patient, it can simultaneously determine the presence of other substances in urine including protein, urobilinogen, ketone, bilirubin, hemoglobin, leukocytes, and nitrite. Assessment of the dipstick test result is done manually by visually comparing the reactive color of each reagent with the dipstick color chart based on their color similarities [1]. This manual interpretation has its weaknesses or failure, including differences in a perception of color, differences in lighting condition, and a failure to read several reagents in a specified time [2]. Color interpretation is influenced by both the selection of color space and the method of color similarity measurement [3]. Color space gives certain values for every represented color. RGB is a default color space used by most of camera sensors and computer displays. Another color space, CIELAB, is commonly used in digital image processing, because it describes color in a representation on how human interprets the color [4].

Color similarity among colors can be determined by calculating their Euclidean distance in a specified color space, and selecting the closest distance. However this measurement method only calculates the distances between a tested color and a set of target colors from a color chart and chooses the closest one as the most similar color. It cannot determine whether a tested color lied within or beyond the color chart range. Moreover, it limits the result to a limited selection as given by the color set of a chart.

In this research, we observe the pattern of color change for each reagent using a stepwise linear interpolation curve fitting in CIELAB color space. This approach gives a better approximation of the dipstick test result if the tested color lies between two target colors in the color chart. It also produces a smoother values interval compare to the manual interpretation. Considering the importance of dipstick urinalysis, an automation method for dipstick test result interpretation is proposed. The proposed method uses the digital color model to determine the color range of each reagent, and performs a similarity examination to compare the tested reagent with its corresponding color range chart. The proposed method should be light in computing implementation, so the application can be developed in a mobile phone platform.

II. METHODOLOGY

A. General Proposed System

The process flow of the proposed method is shown in Fig.1. A color chart from dipstick reagent stick produced by Mindray U-11 is used for this research. Color range of each reagent is observed. Each color from this color range is digitized and used as our reference data. R, G, and B color information of digitized color chart are extracted and transformed into CIELAB color space.

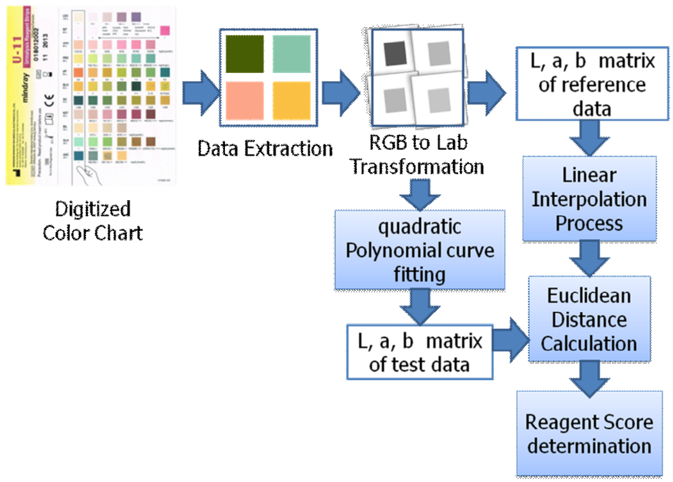

Fig. 1. Process Flow of The Proposed System

Test data are created to simulate possible dipstick test results. They are: (1) test data which are generated from a quadratic polynomial curve fitting as the ideal set of colors, and (2) test data which are extremely different from the known discrete nodes color.

B. Stepwise Linear Interpolation

A stepwise linear interpolation curve fitting for each reagent can be done by mapping its color component L, a, b into a cartesian diagram. Fig. 2 shows the linear interpolation for glucose reagent. X, Y axis defines the level of a reagent, and the value of color component, respectively.

C. Reagent Score Assessment

Our proposed algorithm for assessing the score of the tested reagent is described as follows:

1. Using euclidean distance, calculate the distance between two adjacent reference data, and the distance between a test data and each reference data, as shown in Fig. 3.

$$d = \sqrt{(L_{test} - L_{ref})^2 + (a_{test} - a_{ref})^2 + (b_{test} - b_{ref})^2} \quad (1)$$

2. Find a node n in reference data that has the shortest distance to test data. The value of n represents the location of the selected data.
   a. If $n-1$ is equal to 0, then the node is located on the first level. Assign the node number n as node “B” and the node number $n+1$ as node “C”. Go to step 3.
   b. If $n+1$ is more than the numbers of reference data, then the node located is on the last level. Assign the node number n as node “C” and the node number $n-1$ as node “B”. Go to step 3.
   c. Otherwise, this node is between two nodes. Continue to step 4.

3. Check if the distance between test data to node "B" is longer than the distance between node "B" and node "C", OR the distance between test data and node "C" is longer than the distance between node "B" and node "C", this test data is beyond the color chart range. Skip the next step and mark the test data as an error.
4. Calculate the distance of test data to node $n-1$ and the distance of test data to $n+1$. Find the shortest one and note the node.
5. If the resulted node is $n-1$, check whether the distance between test data and node $n-1$ is smaller than the distance between node $n-1$ and n. If it is true, denote $n-1$ as “B” and denote n as “C”.
6. If the resulted node is $n+1$ check whether the distance between test data and node $n+1$ is smaller than the distance between node $n+1$ and n. If it is true, denote $n+1$ as “C” and denote n as “B”.
7. If both of two conditions on step 5 and 6 above are not fulfilled, this test data is beyond the color chart range. Skip the next step and mark the test data as an error.
8. As shown in Fig. 4, the relationship between test data, B, and C is evaluated using trigonometry model to project the current test node position into its relative position between node B and C. Equation 2 is used for this evaluation model.
9. The tested reagent score can be assessed using Equation 3.

$$Cx = \frac{AB^2 - BC^2 - AC^2}{-2BC} \quad (2)$$

$$\left(\frac{Bx}{Bc} \times (ScoreofC \quad - ScoreofB \quad) \right) + ScoreofB \quad (3)$$

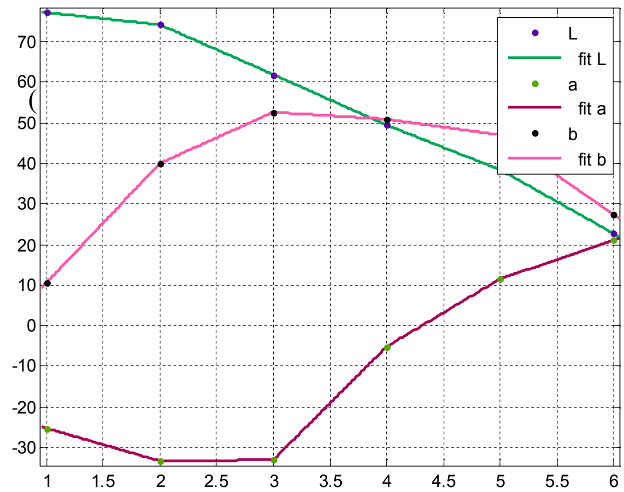

Fig. 2. Linear Interpolation Curve Fitting of Glucose Reagent

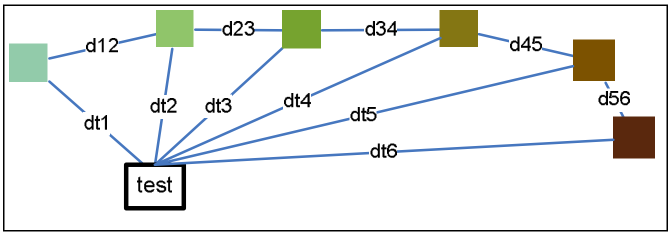

Fig. 3. Test Data and Reference Data Distances Calculation

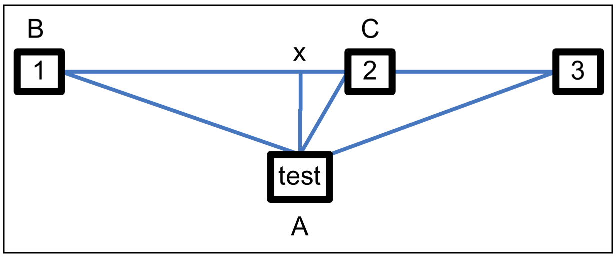

Fig. 4. The Relationship between Test Data, B, and C

III. Results and Analysis

To evaluate the performance of this approach, firstly we evaluate the color similarity accuracy of the automation without curve fitting by comparing a color similarity result of the tested color samples and compare the result with the manual interpretation. This evaluation is performed in RGB and CIELAB color space. Secondly, we evaluate the performance of linear interpolation to enhance the precision of reagent color measurement.

A. *Interpretation of Spesific Reagent*

A glucose reagent is used as an example of interpretation using our approach. As shown in Table 1, we provide 8 test data as possible color generated from polynomial curve fitting, and the rest 4 test data as outlier data.

B. *Reagent Score Assessment Using Proposed Approach*

In this section, Test data 2 is used as an example to be measured by the formula resulted from our algorithm. The score is assessed and described by Equation 4 and 5. The trigonometry model is illustrated in Fig. 5.

$$Cx = \frac{24.16547^2 - 30.66^2 - 10.2494^2}{-2 \times 30.66} = 7.526032798 \quad (4)$$

Score of Glucose =

$$\left(\frac{30.66 - 7.526032798}{30.66} \times (100 - 0)\right) + 0 = 75.4598053 \quad (5)$$

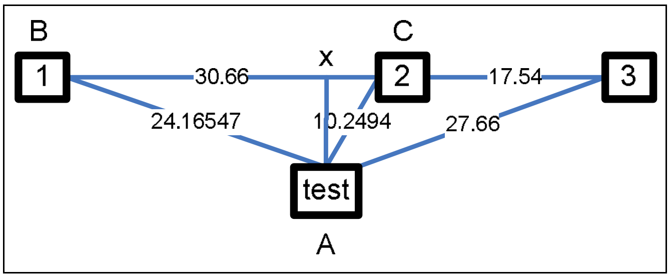

Fig. 5. The Relationship between Test Data 2, Reference Data 1, 2, and 3

TABLE I. Interpretation Result of Glucose Reagent

<table>
<tr><td colspan="5">Reference Data :
–   100   200   500   1000   2000</td></tr>
<tr><th>Test Data</th><th>Color</th><th>Visual Interpretation</th><th>CIELAB Interpretation</th><th>Interpretation with Linear Interpolation</th></tr>
<tr><td>1</td><td></td><td>1</td><td>1</td><td>Score of glucose = 17.27682</td></tr>
<tr><td>2</td><td></td><td>2</td><td>2</td><td>Score of glucose = 75.45981</td></tr>
<tr><td>3</td><td></td><td>2</td><td>2</td><td>Score of glucose = 116.3631</td></tr>
<tr><td>4</td><td></td><td>3</td><td>3</td><td>Score of glucose = 144.4729</td></tr>
<tr><td>5</td><td></td><td>4</td><td>4</td><td>Score of glucose = 364.2841</td></tr>
<tr><td>6</td><td></td><td>4</td><td>4</td><td>Score of glucose = 494.5027</td></tr>
<tr><td>7</td><td></td><td>5</td><td>5</td><td>Score of glucose = 761.6632201</td></tr>
<tr><td>8</td><td></td><td>5</td><td>5</td><td>Score of glucose = 1167.71123</td></tr>
<tr><td>9</td><td></td><td>unknown</td><td>6</td><td>Error</td></tr>
<tr><td>10</td><td></td><td>unknown</td><td>6</td><td>Error</td></tr>
<tr><td>11</td><td></td><td>unknown</td><td>5</td><td>Error</td></tr>
<tr><td>12</td><td></td><td>unknown</td><td>3</td><td>Error</td></tr>
</table>

IV. Conclusion

Color assessment for urine dipstick reagent result interpretation has been done in this study. To simulate and automate the visual interpretation, a color similarity matching is used. The result shows a consistent color assessment. A better approach of urine dipstick reagent interpretation is proposed for reagents which measure a quantity such as glucose or pH. For this purpose an additional linear interpolation is proposed. This approach achieves a higher measurement precision in urinalysis. Our tests shows this achievements, and it can also determine whether the tested data lies beyond expected color range.

Algorithms and formulas which are introduced in this paper has been considered to be easily implemented in a current mobile platform. A smartphone which is equipped with a camera can use this method to be used as a mobile dipstick urinalysis. A method for automatically recognize each reagent in a dipstick urinalysis and automatically calibrate the recorded color is required.

Acknowledgment

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