Robust Classification of pH Levels on a Camera Phone

B.Y. Loh, N.K. Vuong, S. Chan and C.T. Lau

***Abstract*—In this paper, we present a new algorithm that automatically classifies the pH level on a test strip using color image processing techniques. This algorithm is implemented on a camera phone that captures color images of pH test strips for healthcare or medical purpose. Experimental results show that this new approach is more robust in handling reflection and skewed placements of the test strips.**

***Index Terms*—pH test, color image processing, mobile application.**

I. INTRODUCTION

pH tests are widely used to measure the acidic or alkaline level of substances. pH levels typically range from 1 to 14 with 7 being neutral; 1 is highly acidic and 14 is highly alkaline. In a healthy person, the body fluids should neither be too alkaline nor acidic [1]. Thus monitoring the pH level of body fluids is a simple and effective way to check for early indication of various diseases. pH tests can be easily carried out by dipping a pH test strip in the fluid. The pH level is indicated by the color change on the test strip. By visually comparing the test strip's color against a color reference, the pH level of the fluid under test is known. For example, orange is level 3, green is level 7 and blue is level 10. For individuals who find it difficult or impossible to compare the colors visually, we propose a convenient solution using a camera phone - a device that many people own and use in their daily life nowadays.

We have earlier developed and presented a novel assistive technology system for measuring and classifying pH levels from a digital camera phone image [2, 3]. Fig. 1 shows the overall structure of the system.

A mobile phone camera is used to capture an image of the pH test strip and the color reference chart. The image processing unit (IPU) running on the mobile phone identifies the pH level by matching the color of the pH test strip with one of the colors on the reference chart. The result of the automatically identified pH level is displayed on the phone. At the same time, the pH result can be stored in the phone or transmitted to the doctors for further analysis if necessary.

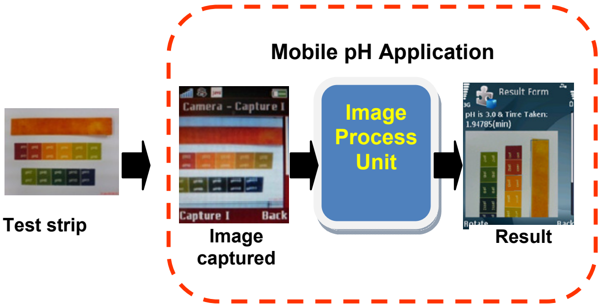

Fig. 1. Structure of the proposed mobile pH application.

The mobile pH application is able to assist individuals who monitor their body fluids for medical and healthcare reasons. This tool is particularly helpful for color-blind patients and elderly people with poor eye sight. It is also beneficial to those with normal eyesight but have difficulties in distinguishing colors that are similar. This automated application may also be helpful to medical professionals such as nurses or doctors who have to conduct and interpret numerous tests daily. This application has several advantages. Firstly, it does not incur much cost since it requires no special hardware other than the camera phone itself. Moreover, it is easy to use with no technical skills required. Thirdly, this software solution can be readily integrated into a comprehensive mobile healthcare system to provide holistic service which can be customized for individual patients. Most importantly, this software tool enables patients to monitor their health regularly in the comfort of their home thus saving time and money that would otherwise be incurred for medical consultations and laboratory visits.

II. PREVIOUS WORKS

The original approach we employed to process images of the pH test strips in a previous study [2] was based on edge detection filters. Sobel edge detection was used to locate those pixels on the edges of the test strip and the color reference strips. Subsequently, simple scan-line and thresholding techniques were used to locate the boundaries of the test strip and the color targets. Eventually, the classification was achieved by measuring color distances between the strip color and color targets. The color region that best matched the color of the test strip (i.e. they had minimum color distance from each other) revealed the pH level of the test strip. Experimental results produced by the edge detection based (EDB)

Manuscript received August 31, 2010; revised January 7, 2011. The authors are with the School of Computer Engineering, Nanyang Technological University, Nanyang Avenue, Singapore (email: ivan.loh@pmail.ntu.edu.sg, {vuon0002, asschan, asctlau} @ntu.edu.sg).

approach were consistent with the ground truth estimation [2]. However, the EDB could not process images whose test strips were skewed more than 7 angular degrees to the horizontal axis.

We then developed an improved approach known as CQB [3] based on Wu's color quantization [4]. It comprised two steps. First we quantized the colors in the original image to two clusters in order to remove the background as well as some noise. Next, the colors in the residual image were quantized to 11 clusters. The cluster with the largest number of pixels was thus identified as that of the pH test strip. The computation speed of this approach was about 20 times faster than EDB. It was also able to handle test strips that were placed in skewed orientations. However, this method did not work well if parts of the image suffered from reflection. Also, CQB did not explicitly identify the numerical pH level but relied on the user to view the result from the residual image displayed.

To overcome the above limitations, we propose a new approach that can robustly handle images in which the test strips are placed in a skewed manner or images that are partially affected by reflection. First, we use the approach similar to EDB to obtain the boundaries of the test strip and the color reference strips. Next, we use K-means clustering to separate the edge points into three clusters. Using prior knowledge of the lengths of the color reference strips, the edge points are automatically identified as three separate sets: one belonging to the test strip, one belonging to the longer color reference strip (pH1-6) and the last one belonging to the shorter color reference strip (pH7-11). This step contributes a major improvement over the previous algorithm because its function is robust even when the strips are placed in a skewed manner. Next, the color reference strips are further partitioned into 11 segments (pH1-11) using the edge points obtained earlier. With prior knowledge of the colors in the color reference strips, a color lookup table is then used to recognize the color reference segments. This is an important enhancement as it helps to recognize the color reference strips even when they are placed in arbitrary orders or orientations. Moreover, by matching against the color lookup table, even if one or two segments of the color reference strips are affected by reflection or other illumination effects, the reference strips can still be correctly identified and the color distortions of the affected segments can be rectified. This greatly improves the robustness of our algorithm. In the final step, the average color of the test strip is matched to one of the 11 color segments in the reference strip to automatically identify the test strip's pH level.

III. IMAGE PROCESSING UNIT

The image captured by the phone camera will go through the sequence of processes as shown in Fig. 2.

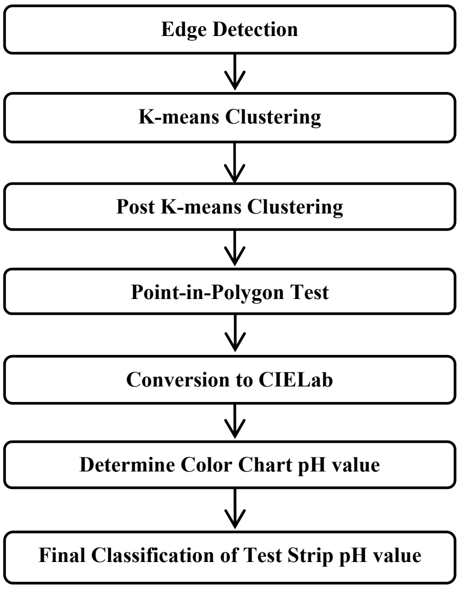

Fig. 2. Sequence of operations in the IPU.

A. Edge Detection

The IPU begins with Sobel Edge Detection (SED) [5] on the image captured. SED is generally used for grayscale images and modification to the algorithm is required for it to be used on color images. The modified process depicted in Algorithm 1 is obtained from J2ME-EDB approach [2].

```
Input: Color image, $Th$ and weight $w_i$ where $0 \le w_i \le 1$ for each
       color band $i$
Output: Binary image containing edges for the input image
$G_x = \begin{bmatrix} G_{x1} \\ G_{x2} \\ G_{x3} \end{bmatrix} = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix}$, $G_y = \begin{bmatrix} G_{y1} \\ G_{y2} \\ G_{y3} \end{bmatrix} = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$
for each 3x3 image sub-area $\begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} & z_{13} \\ z_{21} & z_{22} & z_{23} \\ z_{31} & z_{32} & z_{33} \end{bmatrix}$ of the
input color image:
    for each color band $i$:
        compute: $\frac{\partial f}{\partial x_i} = G_{x1}(Z_{1i})^T + G_{x2}(Z_{2i})^T + G_{x3}(Z_{3i})^T$
        and $\frac{\partial f}{\partial y_i} = G_{y1}(Z_{1i})^T + G_{y2}(Z_{2i})^T + G_{y3}(Z_{3i})^T$
    compute: $|f| = \sqrt{\left(\sum w_i \left|\frac{\partial f}{\partial x_i}\right|\right)^2 + \left(\sum w_i \left|\frac{\partial f}{\partial y_i}\right|\right)^2}$
    if $|f| \ge Th$ then mark the pixel $z_{22}$ as an edge pixel
    else $z_{22}$ is a non-edge pixel
return binary image containing only edge or non-edge pixels
       for the input image
```

Algorithm 1. Pseudo-code for SED of color images.

The output of SED produces an image that outlines all the edges. A further processing returns a set of XY coordinates which identifies all the edge pixels in the image.

B. K-Means Clustering

K-means Clustering is a cluster analysis method that separates a set of points into k clusters or regions where each region has a centroid. An integer k representing the numbers of centroids is first chosen. Next, the distance of a point to a centroid is calculated. Each point has k distances to k centroids. A region consists of all the points that are nearest to the cluster's centroid. At the end of this first iteration, all the points in a region are used to calculate the new position of the centroid. The process is repeated by computing the distance of each point to the new k centroids. The iteration stops when there is no change to the points in each region as illustrated in Fig 3.

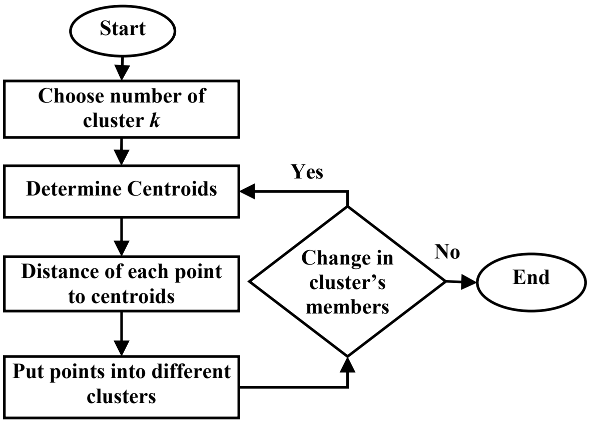

Fig. 3. K-means clustering algorithm.

In our application, k = 3 regions; namely **Test strip**, **Color reference pH 1-6**, **Color reference pH 7-11**. Using k-means clustering, we are able to determine the bounding areas of each strip in 3 iterations as shown in Fig 4.

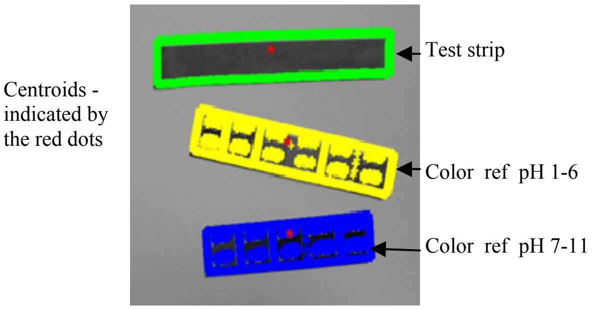

Fig. 4. Complete clustering in 3 iterations.

C. Post K- Means Clustering

After separation of all points into 3 regions, the 4 corners of each rectangular strip are determined by computing the distance of each edge point to the 4 corners of the image. The edge point nearest to the respective image corner is labeled as a corner and the bounded area of the strip is then marked out as shown in Fig. 5. The strip with the longest length is the test strip, followed by the pH 1-6 reference strip and the shortest length is the pH 7-11 reference strip.

Next, the pH 1-6 reference strip is divided into 6 regions and the pH 7-11 reference strip is divided into 5 regions to segregate each pH level into its individual region. Each pH region is bounded by its 4 corners, and their coordinates are stored for use in future steps. The 4 corner coordinates of the test strip are also stored.

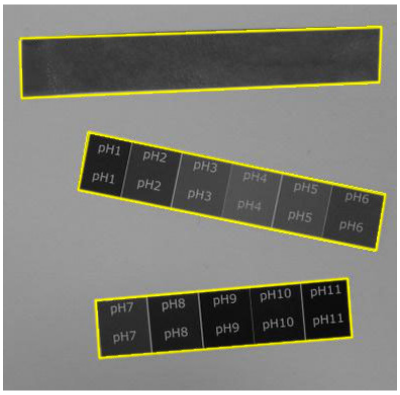

Fig. 5. Bounded regions.

D. Point-in-Polygon Test and Conversion to CIELab Edge Detection

Images from most digital cameras use RGB encoding and a 3x3 linear color transformation is performed to map all the pixels in RGB color space **P** to CIELab reference values **M** using equation (1).

$$\begin{bmatrix} M_{L^*} \\ M_{a^*} \\ M_{b^*} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} P_{red} \\ P_{green} \\ P_{blue} \end{bmatrix} \qquad (1)$$

This step is performed because the difference between any two colors in Lab format can be approximated by treating each color as a point in a three dimensional space (with three components: L, a, b) and taking the Euclidean distance between them [6].

Each pH region consists of pixels which are bounded by the 4 corners whose coordinates have earlier been determined. A point-in-polygon check is performed to determine if the pixel is within the intended region. The application converts all pixels within each region into Lab color space. Pixels that fall outside the regions are discarded.

The entire procedure is performed for all the 12 regions and in addition, a two-pass Lab conversion procedure available in our previous version of the application [2] is used to further eliminate noise and the text in the test strip and color reference strips.

E. Determination of Color Chart pH Value

It might be noted that the position of the 3 strips can be placed in any order. However, it is required that the application has knowledge of the region type and the orientation of the color reference chart. This allows correct identification of the pH value of the respective region after the test strip has been matched to one of the pH regions.

Each pH region is matched to a pre-defined average Lab color as shown in Table I. The average Lab values for the 11 regions are computed based on images obtained from 3 different mobile phones, each with 7 samples taken.

TABLE I
AVERAGE LAB VALUES

pH Region	L	a	b
1	63.625	46.125	15.25
2	75.125	42.875	41.5
3	91.25	25.25	78.375
4	99.625	10.75	74.0
5	95.375	-5.75	79.875
6	90.875	-15.0	75.375
7	83.125	-20.375	58.875
8	72.375	-15.375	25.25
9	61.5	-13.375	5.625
10	57	-3.875	-3.125
11	54.75	2.25	-13.5

The procedure begins by computing the root mean square (RMS) of pH 1 region in the first color reference chart (pH1-6 strip) as compared to the pre-defined average color values of pH1-6. This procedure is repeated for the other five regions in the first color reference chart. Since pH1 and pH6 have diverse color values, we are able to determine which extreme end of the first color chart belongs to pH1 or pH6 based on the RMS result. With this information, the system will also know which region belongs to pH2, pH3, pH4 and pH5. The same procedure is repeated for the second color reference chart (pH7-11) as illustrated in Algorithm 2.

```
Input: pH1-6 color ref chart coordinates ($R1_i$ where i=1 to 6),
       pH7-11 color ref chart coordinates ($R2_i$ where i=7 to 11),
       Original Lab Matrix Vector ($L_i$ where i=1 to 11), Color
       Lookup Table Matrix Vector ($C_j$ where j=1 to 11)
Output: Sorted Lab Matrix Vector
1.  for each Lab Matrix Vector, $L_i$ where i=1 to 6
2.      compute: rmsCol1[i][j] = RMS of $L_i$ to $C_j$ where j=1 to 6
3.      set min1 = rmsCol1[1][1] and minIndex1=1
4.      if min of rmsCol[i][1] < min1 then min1 = rmsCol[i][1],
        minIndex1=i; i=1 to 6
5.      set min2 = rmsCol1[1][1] and minIndex2=1
6.      if min of rmsCol[i][1] < min2 then min2 = rmsCol[i][1],
        minIndex2=i; i=1 to 6
7.      if minIndex2=6 or (minIndex1 >= 4  AND minIndex2 <=
        3) then swop the Lab Matrix for $L_i$ and color reference
        chart coordinates $R1_i$ where i=1 to 6.
8.  end for
9.  repeat 1 to 6 where i=7 to 11
10.     if minIndex2=11 or (minIndex1 >= 9  AND minIndex2 <=
        9) then swop the Lab Matrix for $L_i$ and color reference
        chart coordinates $R2_i$ where i=7 to 11.
11. end for
12. return Sorted Lab Matrix Vector $L_i$
```

Algorithm 2. Pseudo-code for Computation of pH Region Value with Color Lookup Table.

In addition to determining the pH value of each region in the color reference chart, the 11 average Lab values in the color table are used to resolve wrong pH value classification when a part of the captured image has suffered reflection. If the individual pH region Lab value differs by more than 20% from the corresponding Lab value in the average color table, the individual pH region Lab value is replaced with that in the average color table. In cases when the images are affected by reflection or illumination problem, this process provides a more accurate Lab values for the final pH matching and classification.

F. Final pH Classification

With the enhanced Lab values of the 11 pH color chart regions and the knowledge of each region pH value and its coordinates, the final step is to compare the test strip with the 11 pH regions. The RMS of the test strip Lab values are computed against the 11 pH regions Lab values. The region with the smallest RMS indicates that it is the best match to the test strip and is considered as the final pH classification. Fig. 6 shows the result with Lab values in yellow and the RMS value in green. The classification indicates that the test strip has pH level of 3.

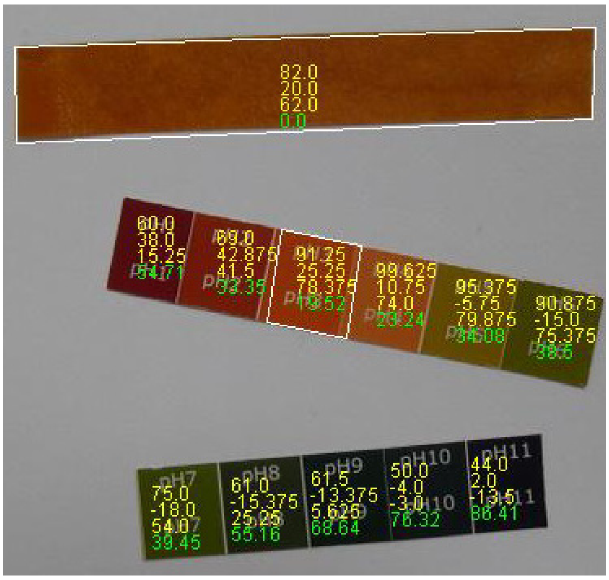

Fig. 6. Final classification of pH=3.

IV. RESULTS AND DISCUSSION

A series of experiments were conducted to evaluate the effectiveness of the application.

Eight test solutions were individually tested with 5 different pH test strips [7] and 5 respondents were tasked to visually match the test strip to the pH value on the color reference chart. Each respondent viewed a different test strip tested on each of the 8 solutions and their responses are collated in Table II.

The same pH strips viewed by the respondents were captured by the phone camera and classified using the application. Each solution has 5 sample images for evaluation. For evaluation of our pH classification application, we compare the results against those obtained by the respondents in Table II. The pH classification results achieved by our application are consistent with those indicated by the respondents.

TABLE II
EXPERIMENTAL RESULTS

Solution Index	1	2	3	4	5	6	7	8
Respondent 1	7	3	3	4	7	9	10	11
Respondent 2	7	3	3	4	7	9	11	11
Respondent 3	7	3	4	4	7	9	10	11
Respondent 4	7	3	4	3	6	9	11	11
Respondent 5	7	4	4	4	6	9	11	11
Application Classification	7	3	3	4	7	9	11	11

Images with reflection and slanted strip placements as shown in Fig. 7 have been tested and the results indicate that the pH values of the test strips are correctly classified by our application.

pH is 2.0 & Time Taken:
1.5530666666666666(min)

Fig. 7. Images with reflection (left) and slanted strip placements.

V. CONCLUSION AND FUTURE WORKS

This paper has presented a robust solution to the problem of mobile pH classification. We have overcome the major limitations in two earlier approaches. This new algorithm is able to handle test strips or color reference strips that are placed in a skewed manner or arbitrary order. It can also automatically identify the correct pH level even when a part of the image is affected by reflection. This is one major step closer to accomplishing an efficient, robust, low cost, accurate, and intelligent mobile pH reader that is of great use to the elderly or color-blind people. In our future work, we intend to focus on the inclusion of different types of pH test strips which can present new challenges due to their different shapes, colors and precisions.

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