UCHEK: AN AFFORDABLE SMARTPHONE BASED POINT OF CARE DIAGNOSTIC SYSTEM FOR A LOW RESOURCE MEDICAL SETUP

Shaakir Mohamed*

**Research and Development Engineer, Biosense Technologies,Maharashtra , India.*
Phone:+919167049088; email: shaakir@biosense.in

Keywords: Urinalysis, reflectance photometry, image processing, mobile-health technology, point of care diagnosis.

Abstract

A point of care diagnosis system comprising of a smartphone and a method for reading the different reagent strips, that performs tests such as routine urinalysis, determining albumin to creatinine ratio and blood sugar tests based on *reflectance photometry*. *uChek* uses the camera sensor as an accurate image sensor, with the help of various image processing algorithms, to capture and perform various diagnostic tests. This system called *uChek* also pushes the data to a cloud database, to help monitor trends and track other useful data, making the results more accessible to labs, doctors and for demographic purposes. This system of diagnosis acts an alternative, affordable technology that not only makes the diagnosis a lot cheaper and suited to a low resource medical setup but also increases the usefulness of the data by recording seamlessly to a database and providing analysis, which helps in early detection and monitoring of treatment for various diseases.

1 Introduction

uChek is a point of care diagnostic system comprising of a smartphone with an app and a test chamber that performs tests such as routine urinalysis, determining albumin to creatinine ratio and blood sugar tests based on reflectance photometry. The key aspect of using a smartphone camera as a sensor makes *uChek* a point of care technology that functions on reliable open source platforms like Android and iOS. This makes the system portable and affordable to environments limited by resources. One of the major drawbacks of the chemical test strips, such as urine analysis test strips are that they can only be read visually either by experienced lab technicians or with the help of expensive semi-automated urine analyzers. It takes much of an effort for a normal user to visually match the colors in a chart with that of the test strips in a stipulated amount of time. It also gets complicated for a user when he or she has to read multi parameter test strips, which are time dependent as well. In order to make the testing process easy and intuitive to any user, it is necessary to automate the process of measurement. Although the commercially available semi-automated urine analyzers provide a solution, these are not affordable enough for small pathology labs and other similar limited resource medical test settings, with shortage of power supply being an additional deterrent. The conventional semi-automated analyzers present in market are also limited by hardware in terms of the type of tests that can be performed with different commercially available strips and the ability to integrate the data to cloud for a more powerful analysis. This system comprising of the smartphone and the *uChek* mobile application bridges this gap keeping the clinical accuracy of the diagnosis in par with the existing expensive semi-automated analyzers and lowering the cost. *uChek* system simplifies this process of measurement and provides lab results in par with the semi-automated analyzers. It also adds the ability of data analytics by pushing the encrypted data to a cloud database, to help monitor trends and track other useful data, making the results more accessible to labs, doctors and for demographic purposes over a secure channel to the concerned authority. Even in the absence of power, a full charge of the smartphone can perform up to 40 tests.This system also ensures easier process integration for various tests within a single system.

uChek was thus conceptualised keeping in mind the need for accuracy and affordability for these labs, which is also helping in improving accessibility of quality healthcare in low resource settings.

2 Method

uChek system uses the smartphone's camera to capture colour change of reagent strips to perform a semi-quantitative analysis. *uChek* system is based on *reflectance photometry*. The camera sensor in the smartphone acquires the image of the dipped reagent strip with a reference color chart, which is then processed using various image processing algorithms for color correction and color matching.

As the reagent strip's reaction to the samples are time dependent, it is imperative that this change in the color of the reagent strips be measured at the right time, hence a timer is used for recording the color change at the right interval. The images of reagent strip along with a reference color chart is captured by the camera sensor at the stipulated amount of time depending on the analyte being measured. For example, in case of a urinalysis strip, the glucose pad has to be

measured at the 30th second from the start of the test. External lighting for the image being captured may be used to get a better image, by utilizing the camera sensor's LED flash.

Once these images have been captured, the images are then corrected for color, by removing any ambient light's effect on the color of the test pads. This is achieved with the help of the reference color chart, which includes colors Red, Green, Blue, Cyan, Magenta, Yellow, White and Grey colors. The colors from the different test pads of the reagent strips are extracted and are then measured with respect to either of the reference colors, for example with respect to white .

After the extraction of the color, in terms of its different components, the system correlates the data between the colors of test pads to the concentration of analytes present in a particular test sample. This involves determining the closest correlation between colors to a predefined set of colors, which correspond to concentration levels of analytes in terms of its different components. The system has to be calibrated beforehand, with the different possible color changes on its reagent strip, resulting with the concentrations of the analytes. The concentration of analyte corresponding to the predefined color, which is closest to the measured color is chosen as the result.

2.1 Image under test

The image captured by the camera sensor consists of the reagent strip along with a reference color chart, which is placed in close proximity to the reagent strip's location. The relative positions of the reagent strip with respect to the reference color chart is also kept constant. As the incident light falling on to the image under investigation, is limited by uniformity in terms of the intensity of reflected light at a particular location, steps have to be taken to control this variation by making sure that the image is captured vertical to the object, keeping the planes of the sensor parallel to the plane holding the reagent strips. Also the test is performed in a closed chamber to reduce any ambient light interference with the reflected light being measured.

The color reference chart plays an important part in the measurement of the color change, as any offset in the colors that can occur due to non-uniformity of light reflected from a surface, can be eliminated by the measuring the proportionate change in the reference color, thereby eliminating any interference caused due to incident light source variations. In order to make the correction effective, it is necessary that the reference colors' are captured or, are placed closer to the reagent strip under test. The closer the reference chart is to the reagent strip, the better will be the similarity in the proportionate color change on both the objects, due to ambient light variation. Also the relative location of the reagent strips to the reference chart has to be fixed, and any variability in its location would cause the correction to be ineffective.

If the position of the reagent strips along with the reference color chart, as an integrated object is not fixed, the process of color extraction becomes complex. This would imply calculating the position of the integrated object's respective test pads and reference color locations, rather than explicitly defining hard coded or fixed locations in an image for color extraction. The positions are dynamically calculated using an object detection algorithm validated in Matlab Software.

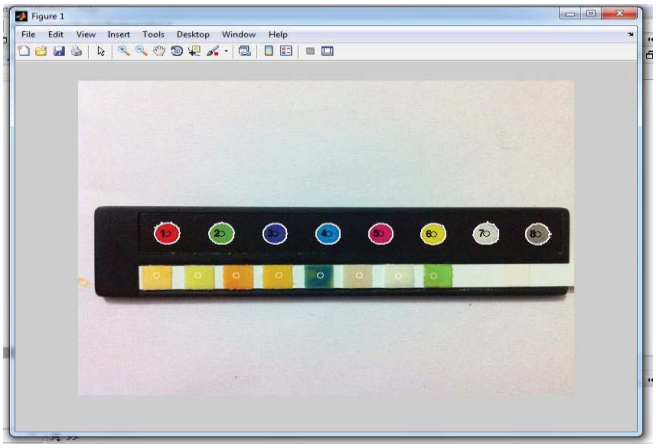

Figure 1: Processed Image after Circle and Test pad detection

The Image is initially resized to 1/4th of its original size maintaining its aspect ratio. The image is converted to grayscale and then to binary image with a calculated threshold found out by experimental data that best suits the object detection. The binary image represents pixels with equal illumination thereby identify surfaces distinguishing them from their boundaries .Removing from the binary image, all objects which are fewer than 300 pixels of area (empirical calculation), helps in identifying the rounded objects and the holes if present, that are filled. The detected objects' areas' are calculated. This helps in elimination bigger areas such as the color reference chart rectangle. A calculation for the roundness of the object is calculated with the equation (1) which defines a threshold. As F tends to 1 the object gets more circular.

$$F=4*3.14*\text{area} / ((\text{perimeter}) \wedge 2) \quad (1)$$

All the objects identified are the reference color chart circles and these 8 circles' centroid and RGB colour values are stored in a matrix. These comprise of Red, Green, Blue, Cyan, Magenta, Yellow, White and Grey circles. If all the 8 circles are not detected then an adaptive threshold algorithm is performed wherein the contrast of the grayscale image is varied from 0.4 to 0.8(based on experimental data) keeping the gamma and the brightness to a value of 1(1 being highest in scale) and the whole object detection is carried out again, by converting the grayscale image to a binary, and selecting the surfaces closer to a circle. Once the 8 circles are detected, the particular contrast value is set for the grayscale image and the reference circles' positions in the image are assigned into an array and the RGB values of circles from the actual image are extracted, by taking a pixel average around the centroid of the detected circles. The Inclination (theta) of the reagent strip along with the reference color chart is calculated with a line

drawn joining the centers of all the 8 circles. The position of the test pads of the test strips are also calculated relative to each of the circles with a calculated scaling and the inclination.

2.2 Colour extraction and matching

The color's of the reference circles and the test pads of the reagent strip under test, are extracted by taking a 5 by 5 pixel average around the centroid of all the relevant positions in the image. The colors are extracted in the form of Red, Green, Blue components whose values range from 0 to 255. The matching process can consist of different color matching algorithms, varying in the color space being used to the method of matching of colors. One of the methods, involves calculating the distance metric in colors. By visualizing the RGB color components as points in a 3 dimensional coordinate system, the Euclidean distance can be calculated for 2 different colors characterised by 2 sets of RGB values. The resulting value indicates how different the colors are. The extracted color's of the reference circles and the colors of the test pads in the reagent strips are calculated with each for their relative difference with each other using Equation (2). A pre-defined set of values is stored representing the closeness of a color of test-pad (indicating the concentration of an analyte) to a particular reference circle. During a test the calculated distances are matched with this predefined array of values, representing the concentration of analytes, by calculating the difference in terms of all its components given by the Equation (2).The least distance or difference value indicates the closest match of a color on a test-pad to a concentration of the analyte.

$$\text{Distance} = (((Rt-Rs)^2+(Gt-Gs)^2+(Bt-Bs)^2))^{1/2} \quad (2)$$

Although this method helps indicate the difference in the two colors, they do not suggest how well the two colors will be perceived by human eye. Hence, the RGB color space is not effective, which means that the distance metric calculated will not match the perceived distance by the human eye. The change in a particular amount of color value should reflect the same amount of change in the color's visual importance, for it to be perceptually uniform. Human eyes are more sensitive towards green than red or blue, and have almost a logarithmic response to brightness. Therefore, it is necessary to convert the RGB components to a Lab Color space model, to best match the perceptual response of the eyes. Lab color space added to its perceptual uniformity has a broader gamut of colors including both the RGB and CMYK gamut. It is also device independent unlike the RGB color space model. The L component closely matches the human perception of lightness. Euclidean Distance could be applied to the L, a, b coordinates for best approximation of the perceptual difference, by considering a color representing a Lab value in a coordinate system.

In case of our image under test, after the extraction of the colors from the test pad of reagent strips in the form of their RGB components, each of the components is first scaled down by 255 to a range from 0 to1.They are then adjusted and converted to XYZ values, from which the Lab values are derived with a white circle as reference. The Lab values are not absolute values unless the white point is set as reference. Here the white reference's RGB values are also undergone the same conversion to XYZ as the test-pad colors. XYZ are encoded using tri-stimulus values of a color, which are a set of 3 primary colors in the additive color space that best represents the color sensation by the rod cells of human eye.

The L values corresponding to the color, which are relative to the different concentration of the analytes are first calibrated into the system. Following the extraction of colors, L values are obtained for the test pads of the reagent strip. This L value calculated is matched with a table representing the L value levels of a particular analyte concentration, thereby obtaining the concentration of the analyte. An example of the same is represented in the Table 1 below.

Concentration of Protein In mg/dL	*L-value thresholds*
Protein Negative	L >79
Protein Trace	74< L<80
Protein 30	68< L<75
Protein 100	59< L<67
Protein 300	49<L<60
Protein 2000	L<50

Table 1: L value variation with Protein Concentrations

2.3 Color space conversion Equations

Both the White reference and the test-pad color should undergo RGB conversion to XYZ: R', G' and B' represent the adjusted values, using Equation (3), Equation (4), Equation (5), sequentially as represented below. Here P is any of the three above mentioned color components R, G, B, and P' their values after scaling with 255.

$$P' = P/255 \quad (3)$$

$$P' = ((P' + 0.055) / 1.055) ^ 2.4 \quad \text{if } P' > 0.0405 \quad (4)$$
$$P' = P'/12.92 \quad \text{if } P' <= 0.0405$$

$$P' = P'*100 \quad (5)$$

$$X = R'*0.4124+G'*0.3576+B'*0.1805 \quad (6)$$
$$Y = R'*0.2126+G'*0.7152+B'*0.0722 \quad (7)$$
$$Z = R'*0.0193+G'*0.1192+B'*0.9505 \quad (8)$$

Xw, Yw and Zw are the corresponding X, Y, Z values of white reference and Xc, Yc, Xc are the corresponding X, Y, Z values of test-pad. These values are divided with each other as represented by Equation (9) to obtain X', Y' and Z'.

$$X' = Xc / Xw \quad (9)$$
$$Y' = Yc / Yw$$
$$Z' = Zc / Zw$$

The Y' component is processed based on the below condition specified in Equation (10) and L value in the Lab color space is calculated using the processed Y', with Equation (11).

$$Y' = Y' \wedge 0.333 \quad \text{if } Y' > 0.00856 \quad (10)$$
$$Y' = (7.787 * Y') + 0.1379 \quad \text{if } Y' <= 0.00856$$

$$L \text{ value} = (116 * Y') - 16 \quad (11)$$

3 Results and Accuracy

Results are displayed in 1-2 minutes depending on the choice of test with an accuracy that is comparable to existing urinalysis bench top machines but at 1/5th the cost. An independent study conducted by *Nanobios Lab, Indian Institute of Technology Bombay* in April 2013, mentions equal and more than 95% accurate results with the semi-automated urine strip reader and visual correlation. In-house accuracy has now gone up to 99% that is being validated at a leading hospital in India. Therefore the accuracy of the system is comparable to the *Uri-Plus 200* and other such commercially available semi-automated urinalysis machines. Pilots with Mobile health vans and telemedicine are providing overwhelming response.

4 Analytics

The system's *uChek* application syncs the data acquired to a server or an appropriate patient record. In case when there is no network available data acquired remains offline in the phone memory and syncs whenever the device is online. This data can also mapped and monitored or tracked to identify any indications. With the help of remote monitoring location, a desktop application is used to maintain the accountability of the location with respect to the usage of *uChek* system and to track and identify the usage rate of urine strips that are used at a particular location.

This ensures the medical set up never runs out of strips. An entry is logged with respect to the corresponding *International Mobile equipment Identity* number of the smartphone every time a test is completed. The results can be analyzed through an online portal, upon a password authentication thereby providing privacy for the data acquired.

5 Conclusion

uChek system depends on the camera sensor's ability to capture colors in the image. As long as the camera sensor is stable in terms of color capturing and perception, uChek system provides an effective way for reading reagent strips.

Acknowledgements

Shaakir Mohamed thanks *Nanobios, Department of Biosciences and Bioengineering, Indian Institute of Technology Bombay* for their constant support.

References

[1] Ben-Ezra J, Bork L, McPherson RA. Evaluation of the Sysmex UF-100 automated urinalysis analyzer. Clin Chem 1998;44:92-95.

[2] Boguslaw Cyganek, Object Detection and Recognition in Digital Images: Theory and Practice

[3] Bolodeoku J, Donaldson D. Urinalysis in clinical diagnosis. J Clin Pathol 1996; 49(8):623–6.

[4] Froom P, Bieganiec B, Ehrenrich Z, Barak M. Stability of common analytes in urine refrigerated for 24 h before automated analysis by test strips. *Clin Chem*2000;46:1384-1386

[5] Hiren P. Patel, The Abnormal Urinalysis. pp. 326-330

[6] J D Peele. Jr, R H Gadsden, and R Crews. A new look at the role of urinalysis in the history of diagnostic medicine.Clinical Chemistry 1991; v. 37, p.119-25.

[7] Lillian Mundt, Graff's Textbook of Urinalysis and Body Fluids, 2010

[8] Mogensen C. Microalbuminuria predicts clinical proteinuria and early mortality in maturity-onset diabetes. *N Engl J Med* 1984;310:356-360.

[9] Peele J, Gadsden R, Crews R. Semi-automated vs. visual reading of urinalysis dipsticks. *Clin Chem* 1977; 23:2242-2246.

[10] Rafael C. Gonzalez, Richard E. Woods, Steven L. Eddins, Digital Image Processing Using MATLAB, 2nd ed.

[11] R S Carel, D S Silverberg, R Kaminsky, and A Aviram. Routine urinalysis (dipstick) findings in mass screening of healthy adults.Clinical Chemistry 1987; v. 33, p.2106-8.

[12] Siemens Healthcare Diagnostics, Your Practical Guide to Urinalysis, 2009, pp. 4–7.

[13] Whelan PV, McGill C, Ng K. Evaluation of the BMC Chemstrip urine analyzer and Chemstrip 10 UA test strip with emphasis on comparison with analytical, chemical, physical , and microscopic methods [Abstract]. *Clin Chem* 1993;39: 1218.