An Alternate Solution for Smartphone-Based Urinalysis

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***Abstract*—Urinalysis is a common medical test that can be costly and inconvenient in medical facilities. The use of point-of-care(POC) test devices, smartphones, manifolds, and other additional tools can make urinalysis easier in a home-based environment. In this paper, we are proposing a new system that can be used to performing a laboratory-free urinalysis with the help of a urine test strip and a smartphone device. Our system contains several image pre-processing steps and an artificial neural network mapping model to analyze the color pixels of the urine test strip. By following our proposed solution, the user can acquire an accurate computer vision integrated urinalysis result.**

***Index Terms*—Point-of-care (POC), Homomorphic filter, Gaussian blur, Otsu, Self-organizing mapping (SOM)**

I. Introduction

According to Meticulous Research, urinalysis tests will reach a market value of approximately $2.21 billion by 2027 [1]. It is one of the most common conducting test in medical cases. The use of urinalysis reagent strip or commonly known as urine test strip or dipstick is a diagnostic tool that is used to determine pathological changes in a patient's body [2] by changing in unique color patterns on the contact of urine. The change of color follows a universal reference color chart. In traditional way, the user need to compare the colors of the strip with the reference chart with bare eyes to determine the test result whereas in medical facilities and laboratories, an automated colorimetric analyzer machine is used to read the data from the strip which worked greatly as a motivation behind our work. This machine is costly according to the market value of 2021. Therefore, a smartphone-based system for urinalysis can be an affordable solution for the home and regular based patients. The aim of this paper is to define a new approach to conduct urinalysis without additional tools except a smartphone and a urine test strip in order to reduce the time and cost consumption in urinalysis.

In the following, we mention several related works in Section II. In Section III, we present our proposed methodology. In Section IV, we have shown the experimental results and the performance accuracy of our proposed system. In Section V, we highlighted some of our limitations and future scope of works. At the end, in Section VI we conclude this paper.

II. Related Works

In recent years, Healthy.io, a US-UK-Israeli based private health-care company conducted research and started an ongoing business startups on smartphone-based home diagnostic testing [3]. Their system uses a special new kind of dipstick. Due to their business policy, their technical method is confidential. On the contrary, we tried to develop an alternative solution for smartphone-based urinalysis with the commonly used urine test strip.

The point-of-care (POC) test is an alternative solution to traditional laboratory-based diagnostics. The most challenging factor in a smartphone-based urinalysis system is the illumination and device independence. Here, we discuss the various approaches and feature extraction techniques applied by different researchers.

The research of Karisen et al. [4] talked about issues of illumination and device independence on integrating smartphones as POC platforms. They achieved illumination and device-independent semi-quantitative detection by using discriminant analysis and classification of simultaneously photographed colorimetric test results and reference colors to confirm that any variation in image conditions applies approximately equal for reference and test. The retraining of classifiers on each analysis is appeared to be the foremost viable solution to solve the challenges while maintaining user-friendliness was a vast limitation.

The use of urine test strip can be seen in the work of T. Smith et al. [5]. They introduced a completely unique manifold and companion software for dipstick urinalysis that eliminates many of the negative aspects. Their results were satisfying but the special manifold was quite a limitation for additional tool free urinalysis.

The ANN self-organizing map (SOM) was explained by Zhang et al. [6], which is considered as a powerful tool for exploratory data analysis and can be employed in a wide selection of color clustering. Their experimental results showed that SOM has the specified ability of clustering color for spread vision tasks. An improved SOM algorithm and its application to color feature extraction were described by Chen et al. [7]. They simply reduced the redundancy of the dominant color features in a colored image while preserving the diversity and quality of the extracted colors are important in applications such as image analysis and compression.

A new image segmentation method was explained by Mohsen et al. based on particle swarm optimization [8]. This method focuses on the mean square error (MSE), which can also be used to refine the result of a similarity condition, which is the smallest difference between means.

III. Methodology

Before we begin our proposed methodology, we must first prepare our sample strip. The urine test strip should be dipped in the patient's fresh urine and placed on black paper or cloth for 60-120 seconds.Then the user photographs the strip in natural lighting condition using smartphone camera. The image will be uploaded to a cloud server whereas our system will work with the image. The methodology's main steps are summarized as follows:

1) The image pre-processing unit filters and crops the image of the strip from the black background.
2) The processed image is used as a sample image in an artificial neural network(ANN) mapping model.
3) The ANN clusters and plots a map of the color pixels from the strip image.
4) A similarity algorithm as mean square error (MSE) determines the final reading of the strip by matching each clustered color pixels with the reference color dataset.

Block diagram of our proposed smartphone-based urinalysis system framework:

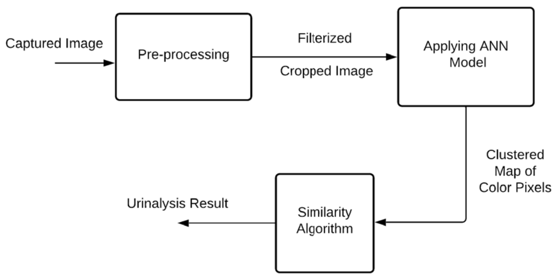


Fig. 1. Block diagram of a smartphone-based urinalysis system framework

Figure 1 shows the system is split into three parts. They are described below:

A. Image Pre-processing

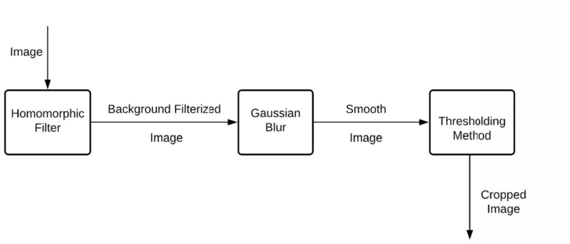


Fig. 2. Block diagram of image pre-processing section

In Figure 2 the overview of pre-processing unit is described. After acquiring the image, we apply the homomorphic filter on the image which involves a nonlinear mapping to a special domain, followed by a mapping back to the first domain using linear filter techniques [9]. After applying, it frequently normalizes the brightness of an image and increases the contrast and remove multiplicative noise. Since the high-frequency components are assumed to represent more the reflectance in the image of the strip, and the low-frequency components are assumed to represent mostly the illumination in the scene, the high-frequency components are increased and the low-frequency components are decreased to make the illumination of an image more equal.
Then we used Gaussian blur, a blurring technique that is used on an image is equivalent to mathematically convolving the image with a Gaussian function. This produces a blur that preserves edges and boundaries better than other uniform blurring filters.
At the end, we used Otsu's thresholding method to minimize intra-class intensity variance [10]. By applying Otsu's method, max contour of the image is now segmented and the system can finally crop the image of the strip from the background image.

B. Applying ANN Coloriemtric Mapping Model

After cropping the image, the next step is to use an ANN based colorimetric mapping model. We experimented with a self-organizing map (SOM) approach on the cropped strip image. This ANN is trained using unsupervised learning to generate a low-dimensional (typically two-dimensional), discretized representation of the input space of the training samples, referred to as a map, and is thus a dimensionality reduction technique [11]. Depending on the implementation of SOM in a color image, it can scan and map the color pixels of the given image systematically.

C. Similarity Algorithm

After applying the colorimetric mapping, a similarity algorithm is needed to match the features with the urinalysis reference color chart. We use mean square error (MSE) method in this part. In this approach the average of the squares of the error, or the average squared difference between the predicted and real values can be determined [12]. The MSE contains the difference between the mapped pixels and reference color pixels which satisfies our purpose eventually.

IV. Experimental Results

The proposed system was initially implemented in Python IDE with Intel Core i7 processor and 8 GB RAM. The graphics unit NVIDIA GeForce GTX 1060 is also used in some certain cases. We then redirect the result to the user's smartphone with a base application.
This section is described in major subsections as dataset description, evaluation of each approaches of the proposed methodology and performance analysis.

A. Dataset Description

The only dataset that is used for this research is the universal urinalysis reference color chart by Multistix [13]. Which is segmented and categorized into 10 folders by labeling them with their primary identities. The dataset can be called by the Python IDE and easily flatten into matrices. Here in the Figure 3 the primary dataset is illustrated with label.

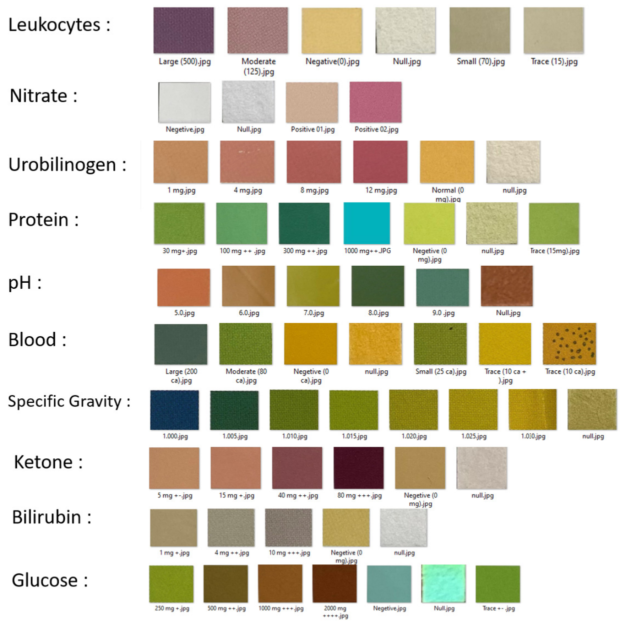


Fig. 3. Dataset created from universal urinalysis color chart

B. Evaluation of Each Steps of the Proposed Methodology:

The image pre-processing system contains the sequence of homomorphic filter, Gaussian blur and thresholding method. The evaluation of image pre-processing section is given below:

(a) Raw Image (b) Homomorphic Filter

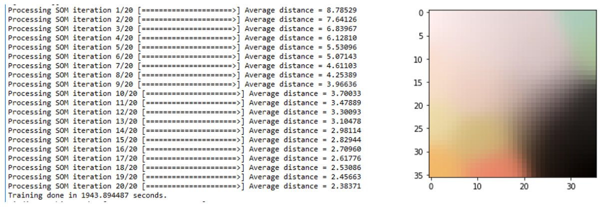
(c) Gaussian Blur (d) Thresholding (OTSU)

(e) Cropped image of the strip

Fig. 4. Image pre-processing evaluation

In Figure 4, the maximum accuracy of cropping the strip from the background image can be seen. The system can crop the image of the strip from a black background in any lighting condition.

After image pre-processing is done, we experimented self organizing mapping (SOM) approach on our cropped image by Numpy library in Python IDE.



(a) Long training session of SOM (b) SOM output

Fig. 5. Applying SOM using Numpy(CPU)

As shown in Figure 5, the SOM output is quite satisfying but the running time is so long (approx 32 minutes for our mentioned CPU). So, we look for an alternative solution for this problem. Since SOM is a graphic integrated ANN model [14], it can be processed through the GPU (Graphics processing unit). Hence, TensorFlow library is used.

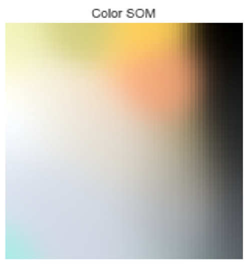


Fig. 6. Applying SOM using TensorFlow(GPU)

In Figure 6, we can see the satisfying result by applying SOM using GPU. The approximate time to get this output is also very minimal.

After obtaining the colorimetric map of our sample urine strip, We call the dataset file in Python IDE and used the mean square error (MSE) method to determine the similarities between the acquired map's color pixels and the dataset in order to finalize our urinalysis result. The minimum mean square error defines the maximum similarity between the color pixels.

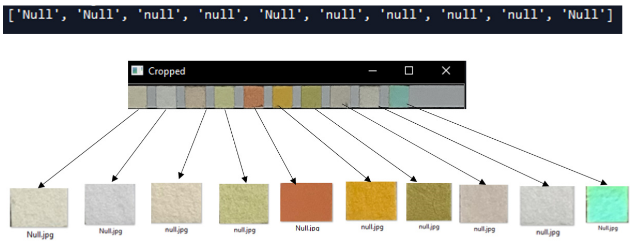


Fig. 7. Mean square error approach result

Figure 7 shows, a not-dipped (no contact with urine) strip was used to test. MSE approach gives a satisfying result by mentioning all the color pallets are "Null".

C. Performance Analysis

Without the "Null" test, we also took samples from 6 volunteered human subjects for experimental testing purposes. The experiment was carried out on the subject's bodily waste (urine), which was a completely non-invasive process with no health risks. We took medical guidance to collect the urine samples. We dipped Uric-10CF strip in our subject's urine and run the diagnosis test in our

TABLE I
RESULT COMPARISON BETWEEN REAL-LIFE AND PROPOSED SYSTEM

Subject ID :	01		02		03		04		05		06	
Age	50		25		45		33		17		23	
Sex	Male		Male		Female		Male		Female		Male	
Urinalysis Parameters	Real-life Result	Proposed System's Result	Real-life Result	Proposed System's Result	Real-life Result	Proposed System's Result	Real-life Result	Proposed System's Result	Real-life Result	Proposed System's Result	Real-life Result	Proposed System's Result
Leukocytes	Trace(15)	Trace(15)	Negative	Negative	Trace(15)	Trace(15)	Negative	Negative	Negative	Negative	Negative	Negative
Nitrite	Negative	Null	Negative	Negative	Negative	Null	Negative	Negative	Negative	Negative	Negative	Negative
Urobilinogen	No-read	Normal	Normal	Normal	No-read	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Protein	Maximum	300mg++	Trace	Trace	1g+	100mg++	Trace	Trace	Trace	Trace	Trace	Trace
pH	7.0	7.0	6.0	6.0	7.0	7.0	6.0	6.0	5.0	5.0	6.0	6.0
Blood	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Specific gravity	1.030	1.030	1.025	1.025	1.030	1.030	1.025	1.025	1.015	1.015	1.025	1.025
Ketone	No-read	Null	Negative	Negative	No-read	Null	Negative	Negative	Negative	Negative	Negative	Negative
Bilirubin	1+	1+	Negative	Negative	1+	1+	Negative	Negative	Negative	Negative	Negative	Negative
Glucose	500mg++	500mg++	Negative	Negative	250mg+	250mg+	Negative	Negative	Negative	Negative	Negative	Negative
Accauracy	90%		100%		90%		100%		100%		100%	

proposed smartphone-based system as well as in the universal urine test reader machine. In Table I the real-data acquire from urine test strip reader machine is considered as x_j and it is compared with the proposed system's result y_j. Here in the following equation 1, $\alpha(x_j, y_j)$ determines if the results match or not.

$$\alpha(x_j, y_j) = \begin{cases} 1 & \text{if } \forall_{x_j} = \forall_{y_j} \\ 0 & \text{if } \forall_{x_j} \neq \forall_{y_j} \end{cases} \tag{1}$$

We follow the equation 2 to determine the initial accuracy per test.

$$Acc_i = \frac{1}{m}\sum_{j=1}^{m} \alpha(x_j, y_j) \tag{2}$$

Here, m is the total number of features to be matched. There are some certain dissimilarities can be seen in some cases of the result because some color pixels have complex matrix structures. The overall accuracy of the proposed system can be determined with the following equation 3.

$$Acc_{avg} = \frac{1}{n}\sum_{i=1}^{n} Acc_i \tag{3}$$

Where n is the total number of conducting tests and Acc_{avg} is the overall accuracy of our proposed system which is approximately 97% in our case.

V. LIMITATIONS & FUTURE WORKS

While working on this paper, we have faced some certain limitations. Although the number of urinalysis test strip was limited, the image pre-processing unit can only work accurately if the image of the strip is taken on a black background. In future works, this limitation could be fixed. On the other hand, the global pandemic COVID-19 was a great hindrance to gather more real-time test data and urinary related patients to conduct more tests. If more data was found, the system could be developed in a robust way. An experimental mobile application can be developed and released for free in order to gather more test data. A test library could be created with the acquired test data and the system could give a fast and more accurate result by using machine learning approaches.

VI. CONCLUSION

In summary, we have proposed a novel system for smartphone-based urinalysis. Several conventional computer vision methods as homomorphic filter, Gaussian blur, Otsu, SOM, mean square error methods are applied to build a workable system and their experimental results are shown. The detected results show that, our method can provide accurate urine test strip reading without any additional physical tools. This method can also be used in the vast field of colorimetric medical diagnosis and disease detection in the agricultural sector.

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