Urine Color Identification by Fuzzy C-means Color Quantization

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Abstract. The urine color can be an indication of the status of health, especially for the patients with urinary catheterization after a medical intervention. Urinary tract infections are the most frequently developed infections among patients receiving treatment in medical institutions. Sometimes signs and symptoms of infection can be observed from the urine color. However, it is a difficult task for nursing staff to correctly identify them on the site with a naked-eye without proper tools. To better assist nursing staff in urine color automatic identification, we have developed a device of urine color identification based on microcontroller unit framework and digital image processing technique of color quantization. The Fuzzy C-means algorithm is applied in the color quantization method. In our experimental results, the developed device with the Fuzzy C-means algorithm has demonstrated its capability of the urine color identification.

Keywords: Urine Color, Fuzzy C-means, Color Identification, Assistive Technology Devices

1 Introduction

Urinary catheterization is a common medical intervention treatment for patients who are long-term bedridden, suffer from a critical illness and have an after-surgery urination difficulty [1]. Patients can develop bacteriuria or a urinary tract infection from long-term catheterization. Urinary tract infections are the most frequently developed infections among patients receiving treatment at medical institutions. Approximately 30 to 40 percent of nosocomial infections are urinary tract infections, and 90 percent of these infections are related to long-term catheter retention. To reduce such infections, nurses must monitor indwelling catheters at all times, help empty urine drainage bags, observe the urine color, and prevent contact infection. Many studies discuss the problems resulting from catheter retention and try to find a better method to avoid urinary tract infection [2,3]. There are two ways to determine that the patient has developed a urinary tract infection. One is urine biochemical tests, which can obtain the number of bacteria and white blood cells; the other one is urine
color observation, which is a rapid assessment indicator in evaluating the status of health [4–6]. Urine biochemical test is an accurate but time-consuming and costly method; moreover, it is not easy for nurses to do such analysis in their daily work. Urine color is a simple and reliable indicator of urinary tract infection, and it can be used to identify the patients’ status of health; however, it is a difficult task for nurses to correctly identify it on site with a naked-eye without proper tools.

Urine color can be an indication of infection, especially for the patients with urinary catheterization after a medical intervention. Nursing staff can early find the signs and symptoms of infection and determine an early treatment for patients by the urine color observation. Related studies on the use of technology in health care have focused on electronic health records, medical image analysis and recognition, the detection and suppression of epilepsy. Related urine color research primarily focuses on pathological and clinical case studies [7–9], with little mention of automatic information technology. To better assist nursing staff in fast urine color identification, we have developed an automatic device of urine color identification based on microcontroller unit framework and digital image processing technique of color quantization. In our previous work [10], we have developed urinary catheterization monitoring device which can automatically empty urine drainage bag, and monitor both urine drainage bag and urine output. The proposed urine color identification device can automatically identify the urine color in the urine bag and work with the urinary catheterization monitoring device. This device can also work independently.

The technique of color quantization [11] is a process that reduces the number of colors in an image or segments of the relevant image regions. In this paper, we apply the algorithm of color quantization to obtain the main color that represents the urine color in the urine bag. In general, algorithms for color quantization can be broadly classified into two categories of algorithms: clustering algorithm and split algorithm. The clustering algorithm of color quantization has better quality color palettes with higher computational cost. The split algorithm has lower computational cost but with low quality color palettes. The best known and most widely used clustering algorithm is the Fuzzy C-means algorithm (FCM) [12]. Since the urine bag is irregular in surface, the color distribution on urine bag surface is not uniform. FCM algorithm is suitable for finding the representative color of the urine bag. The urine color identification device can assist nurses to early find the signs and symptoms of infection with patients.

In the sections below, related works are introduced, and then some experiments that were carried out to evaluate the performance of the device are described. At last, the conclusion is given.

2 Related Works

This section describes the framework of the urine color identification device and the algorithm of FCM color quantization.
2.1 Framework of the Device

The device uses the 32 bits microcontroller unit (MCU) (Parallax Propeller P8X32A chip) [13] as central processing unit. The MCU is equipped with 32KB RAM and 32 KB ROM, and it can work at 80MHz to perform color quantization and signal I/O. In addition, one MCU contains eight processors, called cogs. Each cog contains components such as a processor block, local 2 KB RAM configured as 512 longs (512×32 bits), two counter modules with PLLs, I/O output register, and I/O direction register. The MCU has many advantages, such as low-cost, low power consumption and stability, which is very suitable for a portable device. It communicates with camera and LCD display by transistor to transistor logic (TTL) interface, and transmits data with peer-to-peer by 2.4 GHz radio frequency module (RF). The RF module uses the Nordic NRF24L01 chip and Service Provider Interface (SPI) to communicate with the MCU. The pixel values are 16 bits (rgb format: 565), which are captured from the uCAM-TTL camera. Each pixel needs to be converted into 24 bits color format before color quantization.

2.2 Fuzzy C-means Algorithm

The color quantization of FCM algorithm is proposed by Ozdemir and Akarun in 2002 [12]. In the FCM algorithm, each data point belongs to a cluster with a degree specified by a membership grade. Since the color space of the images and the color clusters contained in this color space are irregular in shape and density, finding representative colors for color clusters is a suitable application area for Fuzzy techniques. FCM algorithm is described as follows.

In the FCM algorithm, \( n \) vectors are partitioned into \( c \) fuzzy groups. The membership values for each point \( u_{ij} \) are normalized, and the sum of membership values is equal to unity, like in the following equation.

\[
\sum_{i=1}^{c} u_{ij} = 1, \quad j = 1, ..., n, \quad (1)
\]

where \( n \) is the total number of pixels in the image, \( x_j \) is denoted as the color of pixel in a color image and is represented as \( (r_j, g_j, b_j) \). With these definitions, the objective function \( J \) is defined as

\[
J = \sum_{j=1}^{n} \sum_{i=1}^{c} u_{ij}^m d(x_j, y_i), \quad (2)
\]

where \( m \) is the parameter of fuzziness, \( y_i \) is denoted as the set of quantization colors. \( d(x_j, y_i) \) is the \( L_2 \) norm and defined as

\[
d(x_j, y_i) = \|x_j - y_i\|^2. \quad (3)
\]

Using the Lagrange multipliers method, the minimization of the cost function results in the membership function
\[ u_y = \left( \frac{1/d(x_j, y)}{\sum_{k=1}^{c} 1/d(x_j, y_k)} \right)^{1/(m-1)}. \]  

(4)

And the update function is

\[ y_j = \frac{\sum_{j=1}^{n} u_j^m x_j}{\sum_{j=1}^{n} u_j^m}. \]  

(5)

The color with the maximum number of pixels is regarded as the main representative color \( \hat{y}(\epsilon \max \{N_k\}) \) from the set of the colors \( \{y_1, \ldots, y_c\} \). After obtaining the representative color, the Euclidean distance \( L_2 \) norm) between the representative color \( \hat{y} \) and the \( k \) th sample in the abnormal urine color database is regarded as the similarity and used to find similar patterns with symptoms.

\[ D_k = ||\hat{y} - y_k||^2, \ k = 1, 2, \ldots, W \]  

(6)

where \( y_k \) is denoted as the sample of abnormal urine color in the database; \( W \) is the number of samples. The most similar sample has the least value among others (\( \min\{y_k\} \)).

### 3 Experimental Results

In this paper, we describe the three experiments that were carried out to evaluate the performance of the device developed by us. The experiments include two methods of comparison for color quantization, urine bag with text, side light and surface folds, and a practical sample. The experiments were performed in 32 bits MCU with the uCAM-TTL serial camera. At once per connection, the camera receives the SYNC command about 37 times until receiving the ACK command from uCAM. It needs 125 sec to capture one image from the camera and transmit it to MCU. Then, MCU transmits one pixel data to uLCD monitor and needs to wait for 10 milliseconds. In the experiments, the images are captured from the partial urine drainage bag. Limits to MCU RAM size, the image size is set as 80×60 pixels, and it needs 48 seconds to transmit from MCU to LCD. For Fuzzy C-means color quantization, the parameters setting as \( n \) is 4800, \( c \) is 2 (one is a representative color of urine, the other is not urine color), \( m \) is 2, \( y_1 \) and \( y_2 \) \((r,g,b)\) are set (64,64,64) and (192,192,192) at initial step.
3.1 Urine Bag with Text, Side Light and Surface Folds

In this experiment, the images of the urine bag with text, side light and surface folds are used to evaluate the FCM algorithm. The original images of the urine bag are shown in Figs. 1(a)~1(d). The quantitative colors $\hat{y}$ are shown in Figs. 1(e)~1(h). Color quantization can be effective for finding a representative color of the urine bag with text, side light and folds.

\[
\begin{align*}
\hat{y} : & (153,156,82) \\
\hat{y} : & (48,46,139) \\
\hat{y} : & (63,53,57) \\
\hat{y} : & (85,17,15)
\end{align*}
\]

Fig. 1. (a)~(d) original images of urine bag; (e)~(h) color quantization results.

3.2 A Practical Sample of Purple Urine Bag Syndrome

In this experiment, a sample of real purple urine syndrome bag is used to evaluate our method. The experimental results are shown in Fig. 2. The image of Fig. 2(a) is adopted from the literature [6]. We set the detection region in the lower part of the urine bag (see Fig. 2(a)). Fig. 2(b) is an image of bag surface with folds and lighting effect. Fig. 2(c) is an image of bag surface with a pipe. Figs. 2(d) and 2(e) are the results of color quantization. By FCM algorithm, the computation time is 109 milliseconds, and the representative color is (62,34,48) in Fig. 2(d). The image of Fig. 2(e) needs 94 milliseconds computation time. The representative color is (68,39,50). In the experiments of Figs. 2(d) and 2(e), the surface folds and pipe can be successfully excluded, and the representative color can be found.

4 Conclusions

In this paper, we have developed a urine color identification device based on the MCU framework the FCM color quantization method to assist nurses in urine color identification in their daily work. The color quantization algorithm can find the representative color and exclude the other colors of surface folds or a pipe. Then, the representative color is compared with the abnormal urine color samples in database to find similar symptoms. Furthermore, the experimental results show the developed device is a practical tool for nurses to early find the signs and symptoms of infection.
Acknowledgment. This work was supported in part by the National Science Council, Taiwan, R.O.C., under grant NSC 100-2221-E-276-003.

Fig. 2. An experiment of practical samples of purple urine bag syndrome: (a) detection region of urine bag [6]; (b)(c) color identification regions; (d)(e) color quantization results.

References