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Prototyping Digital Tongue Diagnosis System on Raspberry Pi

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Abstract: Tongue inspection is a complementary diagnosis method that widely used in Traditional Chinese Medicine (TCM) by inspecting the tongue body constitution to decide the physiological and pathological functions of the human body. Since tongue manifestation is done by practitioner's observation using naked eye, many limitations can affect the diagnosis result including environment condition and experiences of the practitioner. Lately, tongue diagnosis has been widely studied in order to solve these limitations via digital system. However, most of recent digital system are bulky and not equipped with intelligent diagnosis system that can finally predict the health status of the patient. In this research, digital tongue diagnosis system that uses intelligent diagnosis consisted of image segmentation analysis, tongue coating recognition analysis, and tongue color classification has been embedded on Raspberry Pi. Tongue segmentation implements Hue, Saturation and Value (HSV) color space with Brightness Conformable Multiplier (BCM) for adaptive brightness filtering to recognized tongue body accurately while eliminating perioral area. Tongue Coating Recognition uses threshold method to detect tongue coating and eliminate the unwanted features including shadow. Tongue color classification uses hybrid method consisted of k-means clustering and Support Vector Machine (SVM) to classify between red, light red and deep red tongue and further gave diagnosis based on color. This experiment concluded that it is feasible to embed the algorithm on Raspberry Pi to promote system portability while attaining similar accuracy for future telemedicine.

Keywords: Tongue diagnosis prototype, tongue segmentation, tongue classification, k-means clustering, support vector machine

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1. Introduction

A human tongue acts as an inspection medium for disease diagnosis in Traditional Chinese Medicine (TCM). Tongue diagnosis is quite possibly the most generally utilized conventional technique by performing effortless and non-intrusive visual assessment and examination of the tongue credits that has been polished for thousands [1], [2]. This inspection method focuses on color, substance, form, motion [3], coating [4] and geometry features of the tongue [5], [6]. However the major limitation in this practice is the diagnostic result depends on the practitioner's experience and also external environment such as lighting [7]. During the last several years, automated disease diagnosis have been widely studied and developed [8]–[10] in order to qualitatively solve these limitations, increase diagnosis accuracy and increase application value [2], [10], [11].

The advancement of technology and the global primary healthcare support demand enable the platforms for integrated and remote monitoring diagnostics [12]. This has led to research being carried out to develop computational methods of automated disease diagnosis embed in microcontroller, in an effort to improve portability and lightweights, to reduce cost or for use in telemedicine [13]–[15]. Embedded systems have extensive applications in many industries, including in the healthcare, automotive, consumer, and commercial markets [15]. The systems, which can be executed in different applications to make different kinds of diagnosis, are gainful to patients and doctors as they provide portability, mobility [16], and, in some cases of telemedicine, facilitate long-distance diagnosis. Embedded technology also reduces the cost of sending medical information [17].

In this research, a prototype of digital tongue diagnosis system embedded on Raspberry Pi is proposed to promote portability and to reduce human labor. This p prototype performed image processing analysis that include tongue segmentation using threshold method and Brightness Conformable Multiplier (BCM) while Support Vector Machine (SVM) and *K*-means Clustering technique for color classification.

2. Methodology

2.1 Tongue Segmentation

Tongue segmentation algorithm is devised based on the proposed method by Sawabe et al. [18] in 2006. Similar approach by Hou et al. [19] is proposed using grayscale images to discriminate between foreground and background image. This segmentation algorithm employs Hue, Saturation and Value (HSV) color space as threshold variable. Only brightness represented by Value (V) is used as a threshold component to reduce the complexity and is formulated as:

$$V = (max\ \{R, G, B\}) / 255 \tag{1}$$

To segment the tongue area from perioral area, a novel technique also known as Brightness Conformable Multiplier (BCM) threshold technique [20] is formulated using an average brightness value of V_m, a standard deviation, σ, upper threshold brightness, V_{upper} and lower threshold brightness, V_{lower} as shown below:

$$Vupper = Vm + \sigma \tag{2}$$

$$Vlower = Vm - \sigma \tag{3}$$

Here, epsilon brightness, ε is formulated for adaptive threshold brightness control and it is adaptive based on the lighting environment of the tongue acquisition device:

$$V_{upper} = V_m + \varepsilon\ .\ \sigma \tag{4}$$

BCM is formulated to discard the unwanted features (e.g. shadows on the root of the tongue image) that lie on the adjustable brightness safe gap in the transitional brightness boundary [20]. ε is defined as below:

$$\varepsilon = \begin{cases} V_m \ if\ V_{lower} < 2\sigma \\ V_m\,(V_1, V_2, \ldots V_N)\ if\ V_{lower} > 2\sigma \\ V_m^2\ \ otherwise \end{cases} \tag{5}$$

where $0 \leq \varepsilon \leq 1$ and (V_1, V_2,… V_N) is the brightness value V_i for each pixel.

2.2 Tongue Coating and Body Recognition Analysis

The author has formulated the threshold equations (w_1 and w_2) for detecting tongue body and coating based on the HSV colour space and conventional threshold analysis. This formulation will be implemented after segmentation procedures has been executed. K-means clustering method is used to accumulate statistical information (the average color information of every tri-stimulus data) to define the threshold that belongs to substance or coating. In addition, the tongue coating area extracted by the proposed algorithm were validated by the professional doctors in *Kampo medicine*, Kitasato University, Japan.
Existing threshold segmentation method can be defined as:

$$W_{threshold1} = W_{m1} + \sigma_1 \tag{6}$$

Theoretically, Hue, H components present the chromatic pixels based on each colour while Saturation, S defines the intensity of the colour. Value, V represents the brightness value of an image. In this study, H is the dominant attribute that separates the tongue body from the coating area compared to S and V. The author also verified that the colour with a touch of white and yellow reduces the colour information stored by an image or in other words, hue tends to be smaller. Speaking of colour denoted by tongue, tongue with coating has lower Hue as the reddish pixels calculated is lesser. The correlations between hue, H, saturation, S and value, V for coating and body/substance can be expressed as:

$$(S+V)_{coat} < (S+V)_{substance} \tag{7}$$

and

$$\begin{aligned} (V-S)_{substance} &< H_{substance} \\ (V-S)_{coating} &> H_{coating} \end{aligned} \tag{8}$$

The threshold setting judgement parameter to differentiate tongue coating from the tongue body is:

$$w_1 = V - (S+H)/3 \tag{9}$$

Finally, tongue coating can be detected using this formula:

$$w_1 \geq W_{threshold1} \tag{10}$$

Whereby tongue body can be detected using this formula:

$$w_1 \leq W_{threshold1} \tag{11}$$

2.3 Tongue Color Classification

Traditional way of tongue diagnosis manifestation mostly relies on the practitioner experiences and knowledge, which the result can be affected by limitation such as environment lighting. Visual inspection by practitioner's naked eye can lead to misjudgment since the color information or substances on a tongue might look similar. In order perform a fast, high accuracy classification and minimize the ambiguity or other limitations, a two-stage tongue's multicolor classification using Support Vector Machine (SVM) and k-means clustering has been introduced in this research [9].. Firstly, the pre-classification process starts with k-means clustering algorithm that implemented Lab color space to generate most informative clusters (clustering identifiers) as biomarkers to be fed into SVM. By having pre-classification stage, the computational complexity is greatly reduced since the pre-classification process preserves only most useful and contributing colors information.

Basically, *k*-means clustering is one of the simplest unsupervised learning algorithms that solved clustering problems and cluster analysis method that aims to divide and partition data points into k clusters in which each data belongs to the cluster (group) with the nearest mean (based on similarity) [9], [21]. This algorithm consists of two separate phases. For the first phase, this algorithm splits the data image into different clusters of pixels in feature space, where each of them defined by their calculated centroid. Then in the second phase, it recalculates the new centroid of each cluster and new minimum Euclidean distance between each data point will be determined. Euclidean distance is one of the prominent methods that is used to define the distance of the nearest centroid even though there are many other different methods. The centroid for each cluster is the point to which the sum of distances from all the objects in that cluster is minimized [22].

On the other hand, the objective of the SVM is to find a hyperplane line that differentiates two or more classes in an N-dimensional space. Features that fall on the other side of the hyperplane can be categorized as an opponent classes. Fig. 1 below shows the separating classes by SVM hyper plane (A, B and C) to differentiate two informative classes.

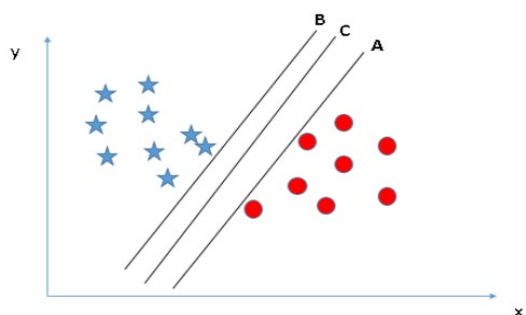


Fig. 1 - SVM classification

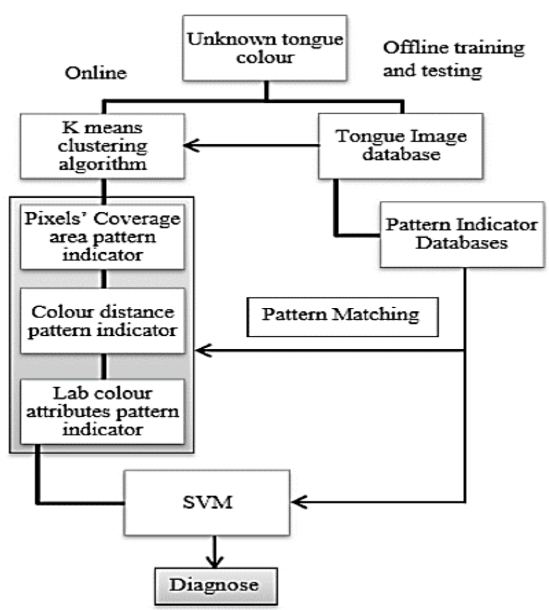


Fig. 2 - Hybrid Tongue colour classification algorithm

In this research, a hybrid classification system comprises of *k*-means clustering and SVM is proposed to classify tongue images into light red tongue, red and deep red based on Complementary Medicine perspectives. In pre-classification stage, tongue image will be categorized using *K*-means clustering into image background, two foreground clusters (deep red region and red/light red region) and transitional cluster. Then, red/light red tongue images are further classified via tongue color gamut range derived in our research. Finally, all the algorithms were embedded into Raspberry Pi where it has been scripted in python language that can execute the scripts independently using built-in python IDLE software in Raspberry Pi.

The proposed automatic tongue color diagnosis system using hybrid method is very useful for early detection of imbalances condition inside the body. According to Oriental Medicine perspectives, tongue can be diagnosed based on its informative features especially colour. Light red tongue is considered normal, red tongue presents body heat and dehydrated while deep red tongue is usually diagnosed with blood stasis. By using this hybrid technique, it is expected that the system will promote higher classification accuracy for diagnosis while reducing the number of support vectors in SVM to improve the execution time in Raspberry Pi.

2.4 Raspberry Pi

Raspberry Pi is a basic small computer system that used Broadcom 2835 700MHz Chip as the processing chip. Besides, it is designed on a CPU core with 32-bit ARM1176JZF-S RISC processor proposed by a group called Advanced RISC Machines (ARM). Its main processing chip connects to a camera and a display. This board can be run on a Linux Debian based operating systems.

The camera module used in this research is Raspberry pi camera module V2.This camera module V2 is able to offer an ultra-high quality 8MP (megapixel) SONY IMX219 image sensor and featured a fixed focus lens. Apparently, this camera module is capable to capture static images of 3280 x 2464 pixels, and also supports videos of 720p60 and 640x480p90 resolutions. The camera module attaches to Raspberry Pi 3B by a 15 pin Ribbon Cable, to the dedicated 15 pin MIPI Camera Serial Interface (CSI) where it is capable of sending extremely high data rates. This camera delivers pixel data to the BCM2835 processor. Fig. 3 shows a system's block diagram for the proposed Tongue Digital Diagnosis Device on Raspberry-pi.

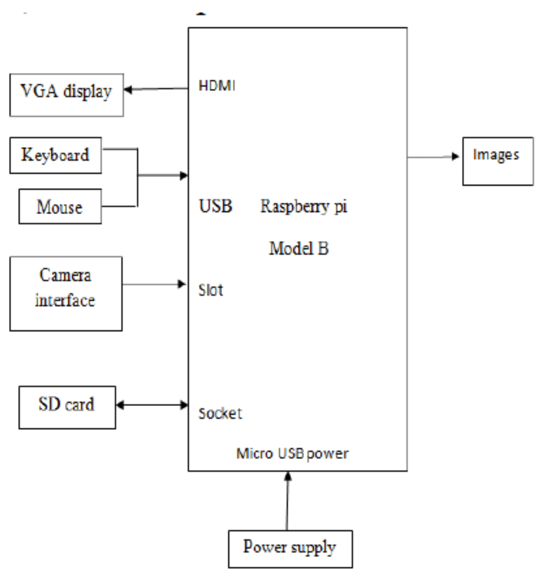


Fig. 3 - System block diagram on Raspberry-pi

Fig. 4 - Connection of Raspberry-pi 3B and camera module V2

3. Results and Discussion

3.1 Tongue Segmentation

According to Oriental Medicine, different kinds of tongue body appearance (e.g normal tongue, pale tongue, red tongue, purple tongue and crimson tongue) characterizes different disease in human body [2], [3]. Nevertheless, there are three basic tongue colours used for tongue diagnosis in clinical practices of Oriental Medicine which is red, deep red and light red as shown in Fig.5 below.

(a) (b) (c)

Fig. 5 - Light red (a), red (b) and deep red tongue (c)

Tongue segmentation process performed based on the overall process flow showed in Fig.6. Firstly, the process started with algorithm read raw image from camera module then create and display a writable copy of the tongue image as in Fig. 7(a). At that point, the interaction continues with the conversion the RGB color image into HSV color before flipping up and modify the image pixel. The flipped image then matched with an array based on the image size while calculating the value of threshold, upper threshold and lower threshold variable value. Fig. 7(b) shows the result of the tongue area that has brightness value lower than the threshold brightness, while the reinverted image in Fig. 7(c) shows the area of tongue body and lips have brightness value higher than threshold brightness. The algorithm then used the BCM to differentiate the area between tongue body area and perioral while removing unwanted features such as shadows and produce final segmentation result in Fig. 7(g).

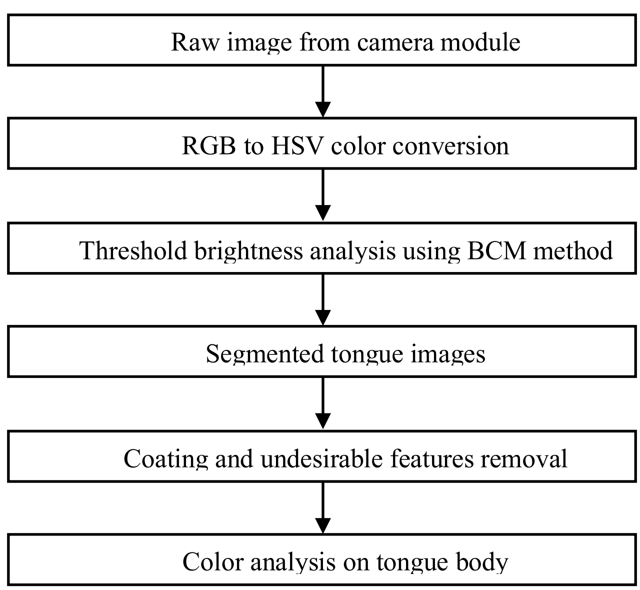


Fig. 6 - Tongue segmentation algorithm flowchart

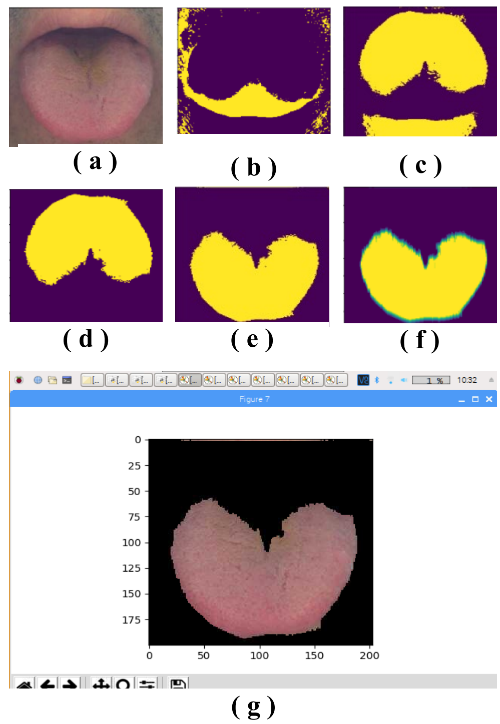


Fig. 7 - Tongue segmentation result in Raspberry Pi

Fig. 8 - Segmented result with unwanted features removal

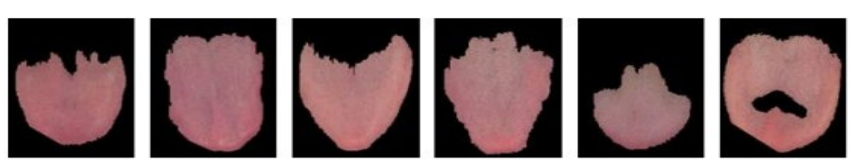
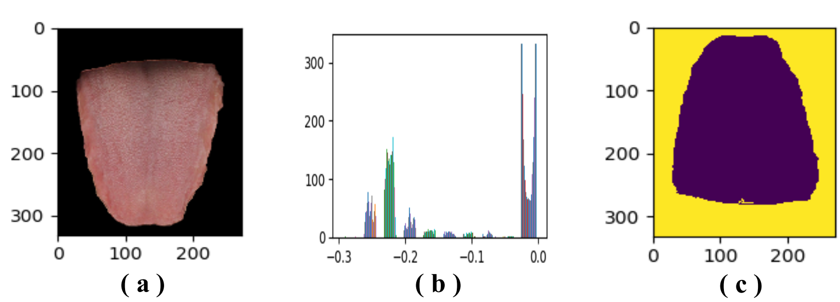


Fig. 9 - Segmented Results after unwanted features removal

3.2 Tongue Coating Removal



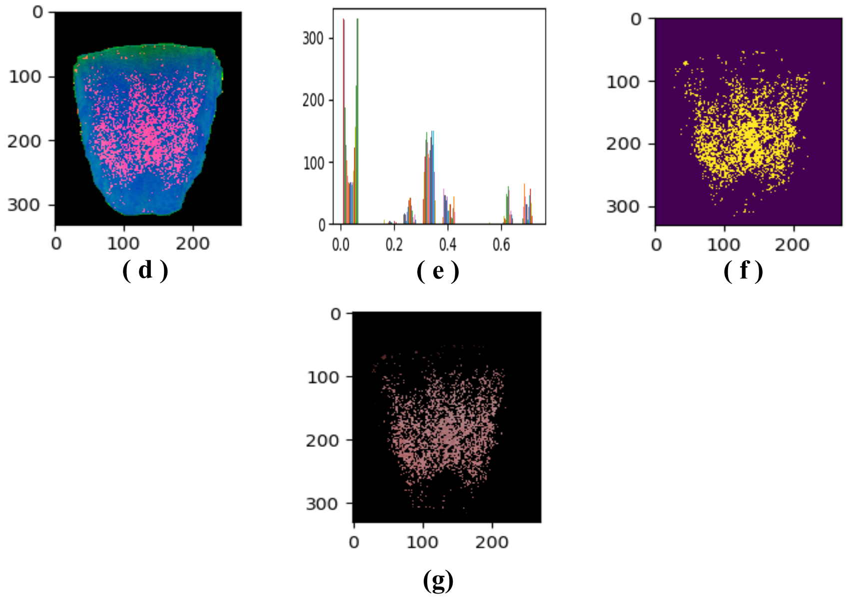


Fig. 10 - Tongue Coating removal result in Raspberry Pi

Tongue Coating removal is a process to eliminate tongue coating and undesirable features such as shadows and light reflection on tongue body for accurate tongue diagnosis. These undesirable features may affect the color analysis of overall tongue diagnosis. The author used adaptive threshold method to eliminate the coating and undesirable features as been explained in the Methodology Section previously. Firstly, the process started with image acquisition of segmented tongue images before been displayed as a writable copy of the tongue image as in Fig. 10 (a). Then, the process continues with masking the array size using return indices of the elements in area that are nonzero, before acquiring the size of the new array to calculate the total pixels of tongue image. The image has been converted from RGB color image to a single-color band and the original image color value is shown via histogram chart as in Fig.10(b).

Fig.10(c) shows the segmented tongue body that have brightness value higher than the threshold brightness. Fig. 10(d) shows the detection area of tongue body, the unwanted features (shadows at the root of a tongue) and a tongue coating area. Fig 10(e) shows the plotted histogram chart of segmented tongue body image and Fig.10 (f) shows the resulted image of coating extracted from tongue body (substance).

3.3 Color Classification

Color classification process started by converting the segmented images to CIE Lab color space. Then the process continues with clustering the CIE Lab color space using *k*-means cluster with the evaluation of Euclidean distance during the first stage of classification. The number of cluster was set to four ($k = 4$) in order to distinguish the surface area of the tongue body that were determined as background color, transitional pixels/tongue coating, deep red pixels of tongue region and red/light red pixels of tongue region[9]. Clustering method of *k*-means algorithm to cluster tongue surface into four clusters was using Euclidean distance metric with centroid detection and color pixels. Deep red pixels of tongue region were determined using maximum pixel's coverage area of CIE Lab color space. Every different pixel of the image was labelled and separated according to its cluster. The second stage classification process starts with both group of data set (red/light red pixels of tongue region) and pattern indicator from pattern indicator databases loaded into SVM algorithm. The algorithm read the images information and resize images of data set according to pattern indicator. In this supervised machine learning method, the algorithm constructs an optimal hyper plane based on the pattern indicator information's. By using the maximum color distance identifier, L* (distance from black pixel) in CIE Lab color, SVM classify test set images into two categories divided by discriminative hyper plane. The prediction was based on the value of L* because this clusters have the least concentration of red in the average of the maximum pixel's coverage area (low a* and b* attributes). Fig. 11 shows the tongue diagnosis/classification results that expressed in terms of number, which is healthy for light red tongue (denoted by 1) and non-healthy for red tongue and deep red tongue (denoted by 2).

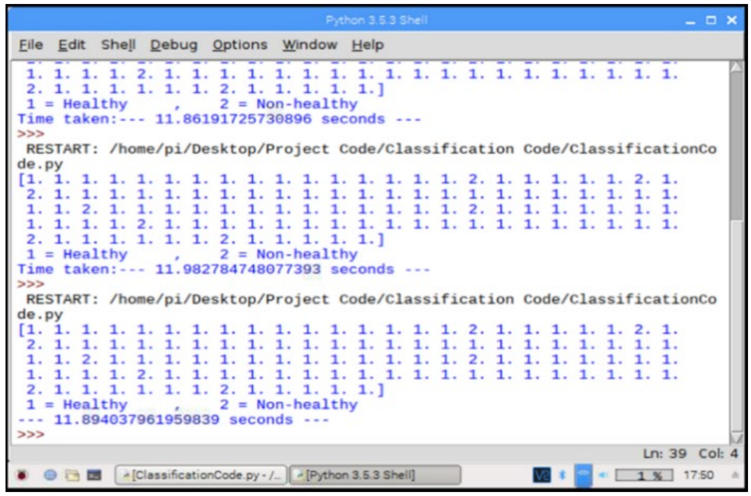


Fig. 11 - Tongue colour classification result in Raspberry-pi

4. Conclusion

This research presents a portable tongue diagnosis prototype system for tongue segmentation, tongue coating recognition and tongue color classification using Brightness Conformable Multiplier (BCM) adaptive threshold, HSV color space threshold and a two-stage tongue's multicolor classification using Support Vector Machine (SVM) and *k*-means clustering. The experimental results have shown the feasibility of execution of proposed tongue diagnosis algorithms on a tiny and low-cost embedded computer, Raspberry pi. We have confirmed that, the accuracy is similar even though the execution time is much higher using Raspberry pi. By and by, this model advances incorporated conclusion framework with versatility and configurable framework that can be helpful for future integrated healthcare system. Future research will be on executing tongue diagnosis algorithm on Field Programmable Gate Array (FPGA) for better performance in terms of execution times.

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