An adaptive computer-aided tongue diagnosis method using colour-calibration preprocessing and multiple feature synthesis based on Android platform

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Abstract: Tongue diagnosis plays a significant role in Traditional Chinese Medicine. Owing to its experience-based nature, an increasing number of researchers have been studying on automatic tongue diagnosis methods. However, most methods fail to calibrate the input tongue images which rely on the quality of tongue images. In this paper, we present an optimised computer-aided tongue diagnosis method based on Android platform which makes up the drawbacks and insufficiency of our previous work. First, it calibrates the colour of the input tongue images and makes them standardised. Then the hue range of the brim pixels of the sample images is evaluated based on maximum likelihood estimate method. This can help us obtain edges and link them into a complete outline to finish tongue segmentation. Finally, we realise the new algorithm on Android platform which can give the classification of the tongue and make diagnosis. Compared to existing calibration algorithms, our system shows better robustness, comprehension and accuracy.

Keywords: colour calibration; feature extraction; tongue diagnosis; Android platform.

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1 Introduction

With its long history, Traditional Chinese Medicine (TCM) plays important roles in China even the whole of Asia. Its usefulness and reliability have also been acknowledged gradually by researchers and doctors in Western countries (O'Brien et al., 2009). Since the tongue can reflect the condition of organs as well as the degree and progression of disease, tongue diagnosis is of great value in TCM. An increasing number of researchers have paid attention to this promising diagnosis method (Anastasi et al., 2014).

In traditional method of tongue diagnosis, doctors determine the syndrome mainly through visual observation and subjective experience, so subjectivity always impedes medical results, affecting the standardisation of the diagnosis; thus, the automatic and quantitative methods for computerised tongue diagnosis based on digital photogrammetry (Zhang et al., 2010), image analysis (Kimura et al., 2010), and pattern recognition (Young et al., 2012; Bunderson and Kuiken, 2012) have developed a lot in recent years.

Quite a few achievements have been made in computerised tongue diagnosis method (Bakshi and Pal, 2010; Ning et al., 2012; Li et al., 2010; Wei et al., 2010). However, most computerised tongue diagnosis methods fail to reprocess the initial tongue image, rendering their methods quite sensitive to the quality of the initial tongue image (Papandreou and Maragos, 2007). It is known that human eyes can compensate for the colour temperature of light falling on an object automatically. However, even the most sophisticated digital camera bears the possibility of distorting the original colours of the images. White balance methods can solve the problem in some degree. Besides the classical Gray World (GW) method, Perfect Reflector (PR) method and Fuzzy Rule method, many enhancement algorithms have been proposed. However, most of them are based on various assumptions so that they cannot adapt to all situations.

GW method and PR method are rudimentary white balance algorithms. However, both of them have their own disadvantages. GW method performs badly when processing monotonous pictures. On the contrary, PR method does well in this aspect but cannot deal with coloured image smoothly. Many recent algorithms stemming from GW, PR just simply combine these two classical methods and conduct experiments without practical applications.

The method proposed in this paper aims to minimise the respective weakness in the existing algorithms, Quadratic Combing GW & PR (QCGP), and solve the core problems developed from GW and PR methods.

Meanwhile, smartphones are around us, providing great convenience in communication. The prevalence and capability of mobile phones offer an ideal platform for our tongue diagnosis system to be practised. Mobile diagnosis, with its feature of convenience and objectivity, ideally solves the defects of traditional diagnosis method and provides a new diagnosis method in the information age. Android system, by virtue of its flexible developing environment, is leading the trend of mobile technology. So the development of the reliable tongue diagnosis system on Android platform not only proves the effectiveness and correctness of our tongue diagnosis method, but also can serve as portable health detectors giving people accurate information about their health, which modernises TCM by leaps and bounds.

The rest of the paper is organised as follows. Section 2 introduces our novel method of calibrating tongue images, outlining tongue edges, and extracting features. Experiment examples and experiment results are presented in Section 3. Finally, concluded remarks and future perspectives are made in Section 4.

2 An adapted automatic tongue diagnosis method based on Android platform

2.1 Colour-calibration method to obtain standardised tongue images

2.1.1 Grey World method

GW estimates the illumination by assuming that a certain standard spatial spectral average exists in total visual field. On the condition that the processed image is abundant in colours, the average reflection will neutralise chromatic aberration. Assume the image $I\ (x, y)$ is of $M \times N$ size, where x and y denote the indices of the pixel position. Furthermore, $I_R\ (x, y)$, $I_G\ (x, y)$, and $I_B\ (x, y)$ denote the red, green, and blue channels of the image, respectively.

Then the average value of R, G and B are calculated as K.

$$R_{\text{avg}} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_R\left(x, y\right) \tag{1}$$

$$G_{\text{avg}} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_G\left(x, y\right) \tag{2}$$

$$B_{\text{avg}} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_B\left(x, y\right) \tag{3}$$

$$K = \frac{R_{\text{avg}} + G_{\text{avg}} + B_{\text{avg}}}{3} \tag{4}$$

Numerate each channel's gain.

$$K_r = \frac{K}{R_{\text{avg}}} \tag{5}$$

$$K_g = \frac{K}{G_{\text{avg}}} \tag{6}$$

$$K_b = \frac{K}{B_{\text{avg}}} \tag{7}$$

Figure out all the pixels' new value in accordance with Von Kries diagonal model.

$$R_{\text{new}} = R \times K_r \tag{8}$$

$$G_{\text{new}} = G \times K_g \tag{9}$$

$$B_{\text{new}} = B \times K_b \tag{10}$$

2.1.2 Perfect Reflector method

The R, G, and B components of the brightest or most reflective spot in an image can be used to scale the RGB values of the other image area. The brightest point is defined as the maximum value of $R + G + B$, or as maximum of Y in YCbCr colour space. First, numerate the threshold value of white reference point, namely T, which is the top 10% of $R + G + B$ (Han et al., 2009). Then traverse all the pixel points in the image, compute S, which equals to average value of the cumulative sum of R, G, B values of the pixels whose $R + G + B$ are greater than T. Finally, quantise the every pixel on closed interval [0, 255].

2.1.3 Integrated white balance algorithm

The above two methods yield good results only if they satisfy certain assumptions mentioned in the preceding part of the paper. The third algorithm combines the merits of both methods with quadratic equation. Take red channel as an example, which is to keep R unchanged.

Calculate the R_{avg}, G_{avg}, B_{avg} and maximum value: R_{max}, G_{max}, B_{max}.

$$K_{avg} = \frac{R_{avg} + G_{avg} + B_{avg}}{3} \tag{11}$$

$$K_{max} = \frac{R_{max} + G_{max} + B_{max}}{3} \tag{12}$$

The correction of green and blue channels is to solve the following equation set, using K_{avg} and K_{max}. Then get u^r and v^r where (u^r, v^r) are the parameters for white balance. This equation is convertible to matrix form, which then can be solved by either Gaussian elimination or Cramer's rule (Strang, 1988).

$$\begin{cases} u^r R_{avg}^2 + v^r R_{avg} = K_{avg} \\ u^r R_{max}^2 + v^r R_{max} = K_{max} \end{cases} \tag{13}$$

The corresponding new pixel values are solved by the equation below.

$$R'_{ij} = \begin{cases} R_{ij} \times u^r + R_{ij} \times v^r & \text{if } R'_{ij} < 255 \\ 255 & \text{others} \end{cases} \tag{14}$$

The processing of G and B are similar to R.

2.2 Tongue outline extraction

2.2.1 Tongue brim pixels searching using adapted HSV model

In our previous work (Wang et al., 2013; Wang et al., 2014; Zhang et al., 2013), we have proposed an optimised computerised tongue diagnosis method with optimised outline extraction algorithm using HSV colour model. HSV stands for hue, saturation and value. We obtain the tongue brim pixel data by searching the lower part of the tongue edge since the upper part tends to be interfered by tongue coating. In this paper, we choose the tongue brim pixel at the one-third location from bottom. We record the hue data in ranges of [0, 0.05] and [0.95, 1], respectively, as red is near 0 and 1 in HSV colour model.

RGB colour model can be represented in HSV colour model as follows:

$$M = \max\left(R, G, B\right) \tag{15}$$

$$m = \max\left(R, G, B\right) \tag{16}$$

$$C = M - m$$

$$H' = \begin{cases} \text{undefined, if } C = 0 \\ \frac{G-B}{C} \text{mod} 6, & \text{if } M = R \\ \frac{B-R}{C} + 2, & \text{if } M = G \\ \frac{R-G}{C} + 4, & \text{if } M = B \end{cases} \tag{17}$$

$$H = \frac{60°}{360°} H' \tag{18}$$

$$S = \begin{cases} 0, & \text{if } C = 0 \\ \frac{C}{M}, & \text{otherwise} \end{cases} \tag{19}$$

$$V = M \tag{20}$$

2.2.2 The maximum likelihood estimate for tongue brim hue range

As the hue data proves to follow normal distribution, the maximum likelihood estimate method can be used for tongue brim hue range (Scholz, 1985). We use normal distribution as the parametric model to estimate the hue ranges, that is:

$$f\left(x|\mu, \sigma^2\right) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{21}$$

We first specify the joint density function for all observations,

$$\begin{aligned} f\left(x_1, \ldots, x_n \middle| \mu, \sigma^2\right) &= \prod_{i=1}^n f\left(x_i \middle| \mu, \sigma^2\right) \\ &= \left(\frac{1}{2\pi\sigma^2}\right)^{\frac{n}{2}} e^{-\frac{\sum_{i=1}^n (xi-\mu)^2}{2\sigma^2}} \\ &= \left(\frac{1}{2\pi\sigma^2}\right)^{\frac{n}{2}} \exp\left(-\frac{\sum_{i=1}^n \left(x_i - \bar{x}\right) + n\left(\bar{x} - \mu\right)^2}{2\sigma^2}\right) \end{aligned} \tag{22}$$

And then we can get a function with variables (μ, σ^2):

$$L\left(\mu, \sigma^2 | x_1, \ldots, x_n\right) = f(x_1, \ldots, x_n \mid \mu, \sigma^2) \tag{23}$$

After transforming the likelihood function into log likelihood function and computing the poles of the function, we can get access to the tongue brim hue ranges:

$$\begin{aligned} 0 &= \frac{\partial}{\partial\mu} \log\left(\left(\frac{1}{2\pi\sigma^2}\right)^{\frac{n}{2}} \exp\left(-\frac{\sum_{i=1}^n \left(x_1 - \bar{x}\right)^2 + n\left(\bar{x} - \mu\right)^2}{2\sigma^2}\right)\right) \\ &= 0 + \frac{n\left(\bar{x} - \mu\right)}{\sigma^2} \end{aligned} \tag{24}$$

$$0 = \frac{\partial}{\partial \sigma^2} \log\left(\left(\frac{1}{2\pi\sigma^2}\right)^{\frac{n}{2}} \exp\left(-\frac{\sum_{i=1}^{n}\left(x_1-\bar{x}\right)^2 + n\left(\bar{x}-\mu\right)^2}{2\sigma^2}\right)\right) \qquad (25)$$
$$= -\frac{n}{2\sigma^2} + \frac{1}{2\sigma^4}\left(\sum_{i=1}^{n}\left(x_1-\bar{x}\right)^2 + n\left(\bar{x}-\mu\right)^2\right)$$

which is solved by

$$\hat{\mu} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad (26)$$

$$\hat{\sigma}^2 = \sum_{i=1}^{n}\left(x_i - \hat{\mu}\right)^2 / n \qquad (27)$$

So the maximum likelihood estimator for the model is $\left(\hat{\mu}, \hat{\sigma}^2\right)$.

We obtain $\hat{\mu}$ with an iterative algorithm as (Sharifi et al., 2002):

$$\hat{\mu}_i = \left(\left(i-1\right)\hat{\mu}_{i-1} + x_i\right)/i \qquad (28)$$

with initial $\hat{\mu}_0 = x_0$. As a result, we set the tongue brim hue ranges to $\left[\hat{\mu} - w\hat{\sigma}, \hat{\mu} + w\hat{\sigma}\right]$ with a weight of w.

2.2.3 An adapted inverted pentagonal four-line tongue outline searching and linking algorithm

First, we obtain five points on the edge: upper left point A, upper right point B, bottom point C, left point D, and right point E. After performing morphological closing on the edge image, we start to apply our optimised search and link algorithm based on the hue range calculated in part b. It starts from an edge pixel. We move this pixel to a new image called outline image. If there is a neighbour edge pixel, we also move it to the outline image and repeat like this; if there is no neighbour edge, search the nearest edge pixel with increasing distance. The distance between two pixels is the sum of their row and column difference. We give different priority to pixels with the same distance in interval AD, DC, BE and EC. In interval AD, the left one is searched before the right one; in interval DC, searching is performed from below to right then from below to left; in interval CE, we search from below to left and then from below to right; in interval BE, we search from right to below, then from below to left. The algorithm is carried out from A to D, D to C, then from B to E, E to C. The upper tongue edge is set as the lowest edge in Canny edge image, as it is located in oral cavity area. Finally, we link A and B with the same search and link algorithm. In interval AB, we search neighbour edge point from right to up, then to down. With all the edge pixels moving to the outline image, we can obtain the final tongue outline.

Table 1 shows how this algorithm performs in interval DC. First, search the neighbour edge pixels from a1 to a5 (from below to right then from below to left). If a neighbour edge is found, move it to the outline image. If not, search the nearest neighbour edge pixels with increasing distance from b1 to b3, then from c1 to c7. The search will terminate once a neighbour edge is found and moved to the outline image.

Table 1 The outline searching and linking algorithm

R, G and B are parameters of a point in the		**D**						
			…					
…	c7	b3	a5	**X**	a3	b2	c4	…
	…	c6	a4	a1	a2	c3	…	
		…	c5	b1	c2	…		
		…	…	c1	…			
	Y			…				
		…						
			C					

2.3 Tongue feature extraction

Tongue features can be acquired through statistics of the pixels of the original image. Tongue coating pixels are those within a hue range near yellow and not excessively big in value. Tongue blade pixels are those within a hue range near red and also not excessively big in value. The thickness of tongue coating is reflected through the ratio of the number of tongue coating pixels to that of total pixels. The tongue is classified by average hue of tongue coating and tongue blade. Pixels with excessively big values are reflection pixels which represent the humidity of the tongue.

2.4 Development of Android application

To make our algorithm more practical, we apply our methods on Android platform. The tongue diagnosis algorithm described above is implemented on Android SDK by Java, and the Android App has been developed for Android system mobile users. After installation, Android system mobile phone users can take photos of their tongue in the app. Then the app can analyse the photos and give out a detailed diagnosis report, which is collected from TCM experts. All of these data will be stored in server, which can be used for further analysis to improve the classification algorithm.

The main advantage of our diagnosis system lies in that it gets rid of the constraint of existing device-dependent diagnosis systems whose images captured from cameras are diverse in luminance and colour temperature. In other words, this Android application avoids the common problems resulting from pictures captured in different environments, and it can be applied in different Android platforms.

3 Example and experiment

3.1 An example of our method

To give a clear description of the performance of our method, an example is given below. We performed our method on the tongue image in Figure 1. The final result is presented on the Android platform.

Figure 1 Initial tongue image

Firstly, we perform our integrated algorithm to preprocess the initial tongue image in order to remove the chromatism brought by illumination. Then we will get the normalised tongue image. The result is shown in Figure 2.

Figure 2 Tongue image after colour calibration

Obviously, the initial tongue image is too dark for further processing. After colour calibration, compensation has been made for the initial illumination condition. As we can see in Figure 2, the colour of the tongue is more standard and the coating can be distinguished from other parts of the tongue more precisely and easily by hue scale. Detailed features such as crackle flaws are more conspicuous and can be easily extracted.

And then the preprocessed tongue image is transformed into gray scale. After removing interfering edges, we get tongue brim edges as shown in Figure 3.

By detecting the pixels inside these tongue edges, we use the maximum likelihood estimate algorithm to get the hue range of the tongue.

After that, we perform optimised Canny algorithm on the gray scale image to generate the basic tongue edges as shown in Figure 4.

Then this hue range is used to distinguish tongue brim from other edges and the general tongue brim can be obtained by morphological closing, as shown in Figure 5.

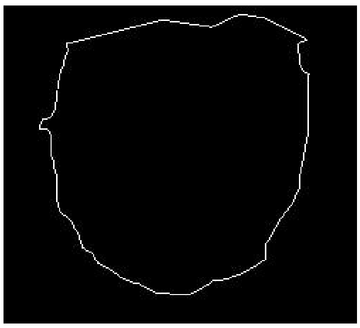
Figure 3 Tongue edges image

Figure 4 Tongue edges image

Figure 5 General tongue brim image

Then a complete and smooth outline can be obtained after adapting inverted pentagonal four-line tongue outline searching and linking algorithm. The result is shown in Figure 6.

Figure 6 Tongue outline image



Finally, we compile the statistics of the pixels in the preprocessed tongue image within the tongue outline and extract features. The tongue area is shown in Figure 7.

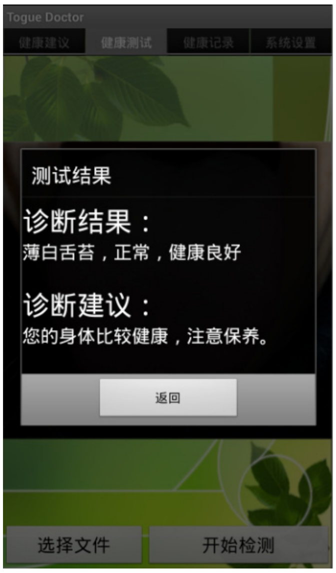
Figure 7 Tongue area within white outline

And the statistics are shown in Table 2.

Table 2 Statistics of the main feature of the tongue image

Feature	*Value*
Thickness	0.1684
Crack	0.0584
Humidity	0.0976

By using the statistics and the features we extract, our method can give classification of the tongue and make diagnosis. The classification and diagnosis are shown below.



The diagnosis is that the tongue is in light red with thin white coating which is normal and healthy. The clinical features suggest that the patient is in good health and more care is needed to maintain the present physical condition.

Table 3 The performance of our method

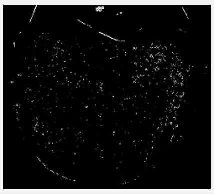
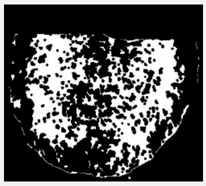
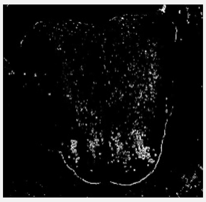
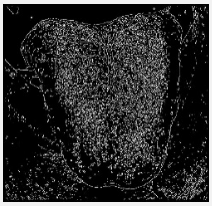
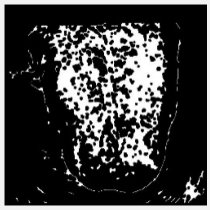
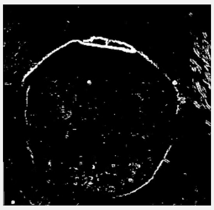
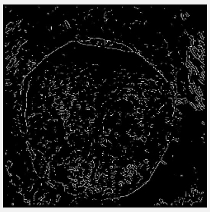
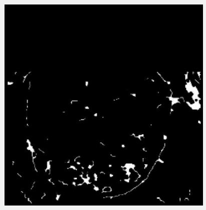
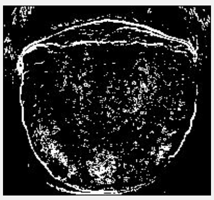
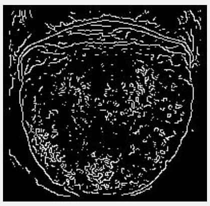
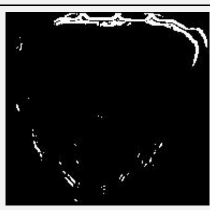
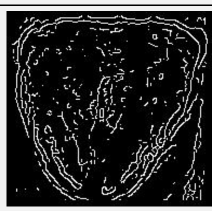
Index	*Colour-calibrated image*	*Sobel edge image*	*Canny edge image*	*Canny close image*
1				
2				
3				
4				
5				

Table 4 The classification and diagnosis of the input tongue images

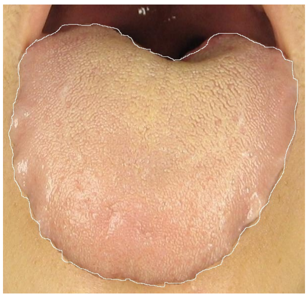
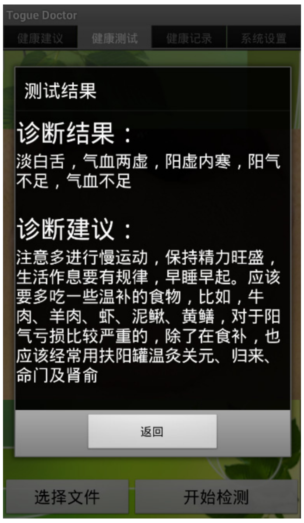
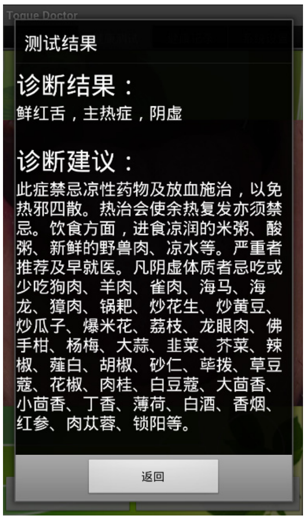
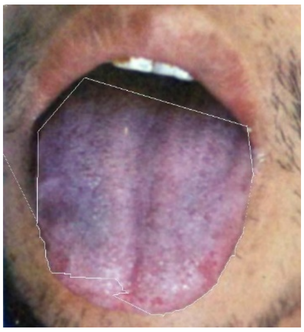
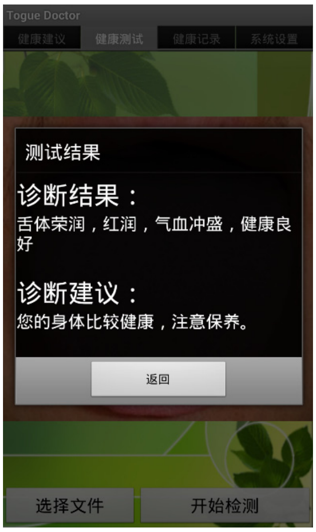
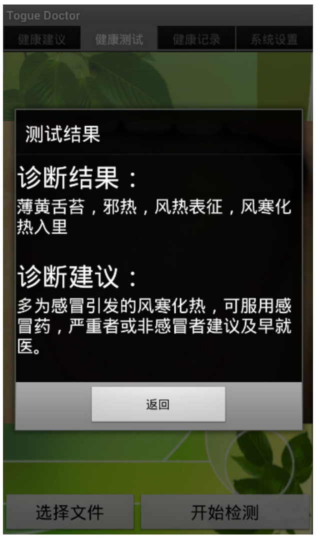
Index	*Tongue outline*	*Classification and diagnosis*	
1			Diagnosis: Pale tongue, deficiency of vital energy and blood Recommendation: Slow in motion, maintain your energy and life routines, keep good hours. Besides eating more warming foods, such as beef, mutton, shrimp, loach, eel etc., the clients can use Fu Yang tank to dredge the acupuncture points in needle warming moxibustion, involving energy pass, vital points, kidney shu, to relieve symptoms
2			Diagnosis: Fresh red tongue with fever and irritability Recommendation: Abstaining from cold medicine, bloodletting treats and pathogenic heat scatters, clients should also avoid warming treats which generate afterheat recidivation. Besides not having hot rice or acidic gruel, cool water, fresh vension, you'd better seek medical advice. Aimed clients are recommended not to inhibit the consumption of dog meat, mutton, sparrow, sea horse, sea otter, rice crust, fried peanuts, fried beans, fried melon seeds, popcorn, litchi, longan, bergamot, waxberry, garlic, leek, shepherd's purse, Chillies, pepper, Fructus Amomi, Alpinia katsumadai, cinnamon, Cardamom, anise, fennel, clove, mint, distilled spirit, cigarette, red ginseng, cynomorium songaricum, etc.
3			Diagnosis: Blue tongue with stagnant movement of blood, yin-cold excess, toxic heat flourishing, dysfunction of lung and liver, damage of the channels and collaterals, possibly results from congenital heart disease or bromatoxism Recommendation: The symptoms can result from many serious cases. Aimed clients are recommended to seek medical advice as early as possible

Table 4 The classification and diagnosis of the input tongue images (continued)

Index	*Tongue outline*	*Classification and diagnosis*	
4			Diagnosis: Tongue with ruddy colour, sufficiency of vital energy in good health Recommendation: Be in good condition and keep up maintenance
5			Diagnosis: Thin tongue with yellow colour, pathogenic heat, wind-heat, chill transmitting heat into innermost of the body Recommendation: Most are results of chill transmitting heat in the symptoms of cold. Aimed clients are recommended to take medicine curing cold. The cases which are serious or are not classified by the cold are supposed to seek medical advice as early as possible

3.2 The experiment results

Tables 3 and 4 show the results and the performance of our method.

Table 3 shows the performance of our method by steps. The first column is the index of the input tongue images. The second column is the standardised tongue images after colour calibration. The third column is the edge images obtained by performing Sobel operators. And the fourth is the basic edge images obtained by Canny algorithm. The images in the last column are the tongue brim images after removing other interfering edges and performing morphological closing.

Table 4 shows the classification and diagnosis of the output images on the Android platform.

4 Conclusions and future perspectives

4.1 Conclusions

In this paper, we propose an optimised adaptive computerised tongue diagnosis method using colour-calibration preprocessing, multiple feature synthesis, and finally we realise it on Android platform. Colour-calibration method can standardise the input tongue image for further processing which reduces the sensitivity to the illumination condition. Besides, a self-adaptive algorithm is adopted to set the hue range of tongue brim and an inverted pentagonal four-line outline-linking algorithm is used to obtain the accurate tongue outline. All prove to be effective for the entire tongue diagnosis process. And the application is able to work on the Android platform and give accurate tongue diagnoses as expected.

4.2 Future perspectives

In our future work, we will focus on optimising our method in order to give more specific medical diagnosis. In addition, we plan to realise our method on other platforms and build a dynamic health database for every single user of our application.

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Note

1 Traditional Chinese Medicine makes use of tongue's characteristics (Gong, 2012), including colour, body shape, coating and moisture, to estimate the health level, thereby come up with corresponding diagnosis recuperating body on judging the exuberance or decline of the genuine qi, distinguishing the nature of disease, detecting the location of disease, and inferring the tendency of disease (or the 'Holism'; Debasis and Sujata, 2010). The diagnosis is based on the comparison with the normal tongue features, like proper size, soft in quality, free in motion, slightly red in colour, thin white coat, neither dry nor over moist, etc. Furthermore, it is popular in TCM recommendation that focuses on the dietary supplement and changing of mood in a long period of treatment. The five classifications in Table 4 are typical cases which indicate most people's tongue images. Furthermore, it is evident that patients are improved by the treatment consolidated by tongue features. As is the main aim of the paper is to standardise the process of tongue diagnosis, overcoming the shortcomings of artificially subjective differences, the detailed information on methodology will not be presented (Chen et al., 2011; Shi et al., 2009) can be regarded as reference materials.