Study of Color Matching System for Porcelain Teeth

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Abstract: Objective: To design and build up a computer-aided color matching system for porcelain tooth, which could offer dentists an objective suggestion for selecting the color of the patient's tooth. **Methods:** The color matching system is mainly based on image analyzing and processing techniques and pattern recognition methods. This system uses HSI color space to compare and calculate colors. The system consists of five parts, which are image acquisition facility, image processing part, tooth color classification module, color mixture module and a template library. This system uses image analyzing technology to find out tooth image's color feature and then look it up in the template library to get the standard term of this tooth's color using pattern recognition methods. **Results and discussions:** Firstly, we use the minimum distance classifier and do two experiments with three tooth models of the identifier 0M1, 3M2 and 5M1. In the first experiment, we take 20 pictures as samples for each tooth model, setting the first 5 pictures as training samples and the last 5 pictures as testing samples. The recognition rate is 66.7%. In the second experiment, we use the former 10 pictures of each tooth model as training samples and the other 10 pictures as testing samples. The recognition is 90%. In addition, we use KNN classifier to test the above test datasets, but the recognition rates are obviously lower than those obtained by the minimum distance classifier. **Conclusions:** The tools and processing platform used in this experiment are simple and efficient. The recognition rate of this color matching system is good and accepted.

Key Words: Biomedical engineering, Porcelain tooth, Image processing, Color matching system, Pattern recognition

1 INTRODUCTION

In this paper, we design a color matching system which is mainly based on image processing techniques and pattern recognition methods, which could help dentists find patients' tooth colors more exactly.

With the growth in living standard, people's demanding in health is increasing sharply. For the dentures wearers, porcelain teeth are used to not only recover the function of the losing or damaged teeth, but also show a healthier appearance. For a better solution, researchers and engineers combine informatics and medicine together [1]. Since the computer is better used in treatment than before, such as using computer to control medical equipment, or support hospital information system, it plays an important role in hospital. Computer-aided diagnosis is widely used, and this is also the best developed area [2]. By combining the computer-aided technology and the manufacture procedure of porcelain tooth, porcelain tooth could be made more like patient's natural tooth on appearance.

In order to make more similar porcelain teeth for patients, doctors always check the color of patients' natural teeth first. In clinical treatments, doctors have two methods to get the description of the color. One way is to use naked eyes to compare patients' teeth with a special tooth model, which is used to represent tooth's color with some identifier, consisted of numbers and letters. But the result gotten through this way is always influenced by the light condition of the environment, or sometimes, a tired doctor would give a bad judgment [3-5]. The other method is to find out the color of a tooth using machine. While naked eyes are easily affected by surrounding conditions, computer-aided color matching system could give an objective result with a fixed color matching environment. Also, computer never feels tired, and it could assess the color objectively.

Now, there are several well-known tooth model brands. VITA Easyshade Compact of VITA Zahnfabric H. Rauter GmbH & Co.KG in German and Crystaleye of OLYMPUS OPTICAL CO., LTD. in Japan make considerable share of the market. These two products are stable and reliable in operation. But the results of some experiments show that the tooth color found out with the help of apparatus is not as trusted by the patients as the color found by doctors [6]. Besides, the price of these apparatus is expensive, so lots of clinics prefer not to use this kind of machine when judging tooth color. Therefore, it is significant for the development of oral medicine to design a computer -aided color matching system for porcelain teeth which would give a better result, and cost less [7].

2 METHODS

2.1 System Design

The design purpose of Color Matching System for Porcelain Teeth is to build up a system which could find the color of tooth, using computer techniques including pattern recognition, image analyzing and processing. This system is able to give dentists an objective classification suggestion in the porcelain tooth models according to the image from the patient's tooth. The system function graph is shown as Figure 1.

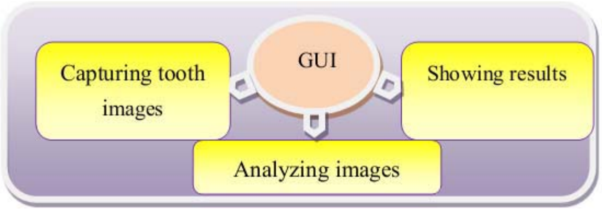


Fig 1. System function graph.

To meet these requirements, the system should contain the following five parts:

Digital image acquisition module: Gather tooth images with designed instruments, which could obstruct the influence of the environment when the images are taken.

Image processing module: Analyze tooth images with image processing techniques. This part can segment the images of teeth, and extract color features of teeth.

Template library: Provide a tooth color context as a reference for the following steps and modules.

Tooth color classification module: Use pattern recognition to classify tooth images into different groups according to their color features.

Color mixture module: Mix the color components in the template library to find the most similar color to a natural tooth's.

This system is built up in Matlab platform. The porcelain tooth model is VITA Toothguide 3D-MASTER as Figure 2. This tooth model contains 29 tooth models with 6 grey levels, 5 saturation levels and 3 hue levels [8]. The 6 grey levels are valued as 0,1,2,3,4 and 5, 5 saturation levels are valued as 1,1.5,2,2.5 and 3, and 3 hue levels are labeled as L,M and R.

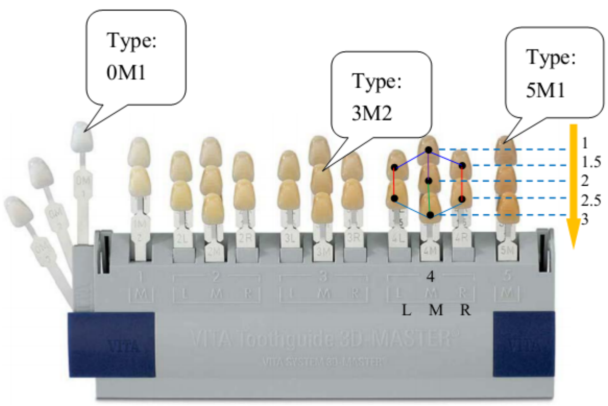


Fig 2. VITA Toothguide 3D-MASTER model.

2.2 Acquire Tooth's Digital Images

To provide images with plenty of information and high clearness, digital image acquisition module should be designed as these aspects:

The target is natural tooth or model tooth on tooth model, whose surface is glossy. The reflection of light would cause error, when analyzing the images. Therefore, the reflection should be abandoned when gathering tooth images. After some trials, we choose to take photos with a camera in the shape of pen, which has micro LED lights in the front of the camera. And the angle between the camera and the surface of tooth is 45°. In this way, the reflection could be avoided.

A suitable dark room and illuminant could offer a recoverable photo. That means the influence of the environment is reduced to nearly 0.

Otherwise, tooth is small in scale, so the camera should be able to take photos in a short distance. Considering all these requirements, the photo taken model is designed like this in Figure 3.

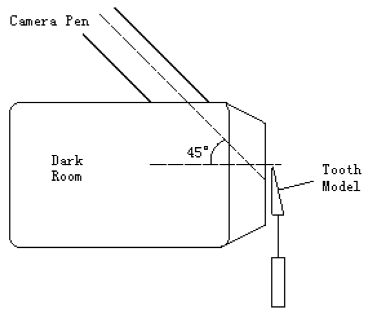


Fig 3. Images acquisition device.

2.3 Build the Tooth Image Datasets

In clinic, the tooth model is the most useful tool to help dentists find patient's tooth color. Some tooth models are frequently-used, for example MK95, ShoFU Vintage, Ivoclar Chromascop and the latest VITA Toothguide 3D-MASTER. According to scholars' researches and dentists' clinic trials, VITA Toothguide 3D-MASTER covers a larger grey level and satisfies most patients' needs in chroma value. Also, this kind of tooth model's color is very stable, and the matched porcelain powder is favored by dentists. So this study chooses VITA Toothguide 3D-MASTER to build the template library.

This tooth model's naming rule is easily understood. Every tooth model has its own name. The first number in its name represents its grey level. The grey level covers 0-5 six levels. The letter in the middle shows the chroma of the tooth model, while M means middle, L and R means that tooth is a little bit yellow or red. The last number is the saturation level.

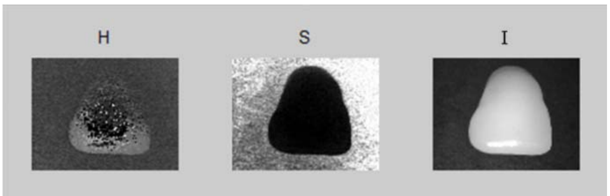
Color of one object is decided by its own color, but sometimes it is affected by the light condition of the environment. When dentist compare patient's tooth with tooth model, the color of the light around would have influence on dentist's decision. In order to remove the effects, we design a darkroom-case for images gathering. With this case, images of every tooth model are taken without disturbing by the environment. In this way, we build up a template library of the tooth models. There are 29 tooth models in Vitapan 3D-MASTER Toothguide, and for each model, we take 20 photos in the same light condition.

2.4 Segmentation of Tooth Image

After the image acquisition, the color-information of tooth images is stored in computers in the form of RGB. Since we need the color features of these teeth, we should segment the tooth out from these images [7][9].

2.4.1 HIS Color Space

Before segmentation, we transfer the image from RGB space to HIS space. HSI color space stores color in three components: hue, saturation and intensity. Such color representation works most similarly to human eyes [10]. And with the intensity component, we could segment the tooth easily. Also, hue and saturation are the other two elements used to distinguish different tooth samples in the tooth model. Besides, in this color space, color components and intensity component are independent, so they won't disturb each other when segmenting and stretching color features. Figure 4 shows the three components in HSI color space of one picture.



(a)Hue component (b) Saturation component (c) Intensity component
Fig 4. The HSI components of tooth image.

2.4.2 Tooth Segmentation

We could segment one picture into foreground and background. The threshold value is important in this step [11] [12]. If the value is too small, there would be too much noise in the result; while if the value is too large, the resolution will be reduced.

Firstly, we calculate the picture and draw the grey-level histogram as Figure 5. It is easily to find that there are two peaks in the histogram, which means we could obtain the threshold effectively.

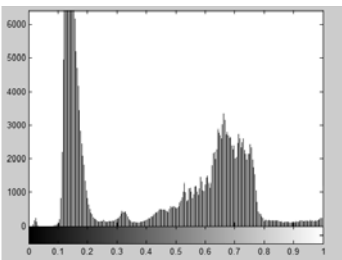


Fig 5. Grey-level histogram of intensity component

To segment the tooth from image, we should make sure where the tooth's location is. In this paper, we use projection to do the orientation. First, we gather the projection on X-axis and Y-axis of the mathematical morphology processed image. After projection, we decide to cut a small tooth area out, and with the friendly GUI. We can get the dashed rectangle region and remove the edge region of tooth image as Figure 6, because this edge region will reflect light when taking tooth pictures. The dashed rectangle region shown in Figure 6 is described in Figure7，we choose the central region V in this rectangle as ROI (region of interest). Therefore we can acquire better information in this region.

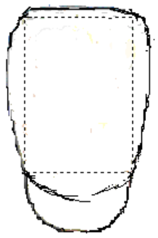


Fig 6. The tooth model graph

I	II	III
IV	V	VI
VII	VIII	IX

Fig 7. Nine sub-areas illustration.

2.4.3 Feature Extraction

PCA (Principal Component Analysis) is known as one of the most popular methods for feature generation and dimensionality reduction in pattern recognition. PCA achieves a linear transformation of a high-dimensional input vector into a low-dimensional one whose components are uncorrelated [13-15].

The theory of PCA: Let $\Gamma_X = \{x_1, \cdots, x_l\}$ be a set of training vectors from the n-dimensional input space R^n. The set of vectors $\Gamma_Z = \{z_1, \cdots, z_l\}$ is a lower dimensional representation of the input training vectors Γ_X in the m-dimensional space R^m. The vectors Γ_Z are obtained by the linear orthonormal projection

$$z = W^T x + b \tag{1}$$

where the matrix $W[n \times m]$ and the vector $b[m \times 1]$ are parameters of the projection. The reconstructed vectors $\Gamma_{\widetilde{X}} = \{\widetilde{x}_1, \cdots, \widetilde{x}_l\}$ are computed by the linear back projection

$$\widetilde{x} = W(z - b) \tag{2}$$

obtained by inverting (1). The mean square reconstruction error

$$\varepsilon_{MS}(W, b) = \frac{1}{l} \sum_{i=1}^{l} \left\| x_i - \widetilde{x}_i \right\|^2 \tag{3}$$

is a function of the parameters of the linear projections (1) and (2). The PCA is the linear orthonormal projection (1) which allows for the minimal mean square reconstruction error (3) of the training data Γ_X .The parameters (W, b) of the linear projection are the solution of the optimization task

$$(W, b) = \arg\min_{W', b'} \varepsilon_{MS}(W', b') \quad (4)$$

subject to

$$\langle w_i, w_j \rangle = \delta(i, j), \forall i, j \quad (5)$$

where $w_i, i = 1, \cdots, m$ are column vectors of the matrix $W = [w_1, \cdots, w_m]$ and $\delta(i, j)$ is the Kronecker delta function. The solution of the task (4) is the matrix $W = [w_1, \cdots, w_m]$ containing the m eigenvectors of the sample covariance matrix which have the largest eigen values. The vector b equals to $W^T \mu$, where μ is the sample mean of the training data.

We could get HSI data in ROI of all these tooth image samples. Using PCA decreases the dimensions of these color component vectors [16][17]. And these are the extracted PCA-based color features.

2.4.2 Methods of Classification

There are many methods to do the classification. In this paper, we choose minimum distance classifier and KNN (K-nearest neighbor) classifier.

Minimum distance method takes these PCA-based color feature vectors as coordinates. First, we divide these coordinates into two sets, training set and testing set. Calculate all the mean values of the PCA-based color features of every type of tooth model in training set. Then compare the coordinates in the testing set with these mean coordinates to see which type's mean coordinate is the nearest one, and then this test sample belongs to this type.

In pattern recognition, the KNN is the simplest one of all machine learning algorithms. An object is classified by a majority vote of its neighbors. It is easily to understand, and costs large storage as well. In Figure 8, the test sample in the diagram belongs to type A.

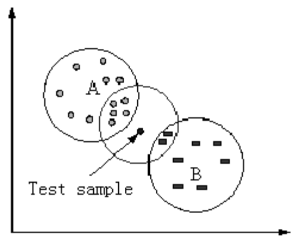


Fig 8. Graphical representation of KNN.

In this paper, we also use a nine sub-areas algorithm to classify these pictures.

First, we get the scale of the segmented training image, and describe it M*N pixels.

Second, we cut it into nine sub-area, the X-coordinate: [0, M/3] [M/3, 2M/3] [2M/3, M], and the Y-coordinate: [0, N/3] [N/3, 2N/3] [2N/3, N].

Third, calculate mean values of each sub-area's color feature and record them in the template library.

Finally, calculate the color components of test pictures in this way, too.

3 RESULTS AND DISCUSSION

Firstly, we use the method of minimum distance classifier. We choose three tooth models with identifier 0M1, 3M2 and 5M1 and take 20 pictures as samples for each model. There are two experiments performed using the minimum distance classifier.

In the first experiment, for each model, we set the first 5 pictures as the training samples and the last 5 pictures as the testing samples. Therefore, there are 15 testing samples for three models. The result is shown as the 15 samples group in Table 1.

The recognition rate is 66.7%. We speculate that the recognition rate would rise up with more samples. Therefore, we add more samples in the next experiment.

The second experiment is still about the three models. This time, we don't change the number of pictures as samples for each model. We just change the training set and the testing set. We use the former 10 pictures as the training samples and the other 10 pictures as the testing samples. Therefore, there are 30 testing samples for three models. The result is shown as the 30 samples group in Table 1. From this table, it could be found that the recognition is 90%. The more samples, the better this method works, therefore large group of samples can reduce errors.

Table1. Classification results by minimum distance method

Correct samples	0M1 type	3M2 type	5M1 type
15 samples in test dataset	4	3	3
30 samples in test dataset	10	10	7

To compare the two methods, we also use KNN classifier to test the above test datasets, but the recognition rates are obviously lower than those obtained by the minimum distance classifier.

4 CONCLUSIONS

This paper designs a reliable computer-aided system for porcelain tooth color matching. The method based on the pattern recognition is presented to classify the tooth models. The tools and processing platform used in this experiment are simple and efficient. The recognition rate of this color matching system is good and accepted. This computer-aided method could provide a valuable support to dentists when they choose the tooth model to make the porcelain tooth for the patients.

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