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A DECISION SUPPORT SYSTEM FOR COLOR MATCHING IN DENTISTRY

VASILE PREJMEREAN, VASILE CIOBAN, ALEX GHIRAN, DIANA DUDEA, AND BOGDAN CULIC

ABSTRACT. Color is very important in oral medicine. This article presents a few solutions to problems that arise in dental image color analysis. Images taken by a digital camera are calibrated (using *VitaPan 3D Master* and *18% Grey Card*) and, afterwards, the colors that appear in various areas of interest are analysed. The user interface uses the CIE $L^*a^*b^*$ color space and for color comparison the ΔE^*_{ab} distance metric is used. The aim of this article is the development of software capable of color analysis performed on a digital image of a dental tooth structure or restorative surface. The analysis of digitally recorded images, performed by computers, may provide important information that can help dentists in achieving superior results.

1. Introduction

The instrumental methods for dental color analysis have been introduced in practice in order to transform a subjective analysis into an objective method, which allows the numerical expression, through different systems, of dental color parameters. As a result, variations induced by particularities of individual perception are avoided, as well as the errors generated by the phenomenon of metamerism.

In the current climate of dentistry the most used tooth shade selection methods are subjective. The methods depend on the observer, who has to compare tooth color with selected shade tabs from different shade guides.

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The recent technological improvements in the area of computers, communication networks and the Internet have greatly affected contemporary society [10], [11]. These improvements have translated in an ongoing improvement of dental medicine. A new generation of technologies focused on the analysis, communication and color checking were developed in recent years. Spectrophotometry, Colorimetry and Digital Image Computer Analysis are the instrumental methods used in dental practice and research ([2], [3]). The instrumental dental color selection methods require the purchase of expensive equipment, which may require specialized training, and which is generally outside the available means of dental laboratories and surgeries, both in Romania as well as abroad. As result, these techniques are rarely used in current dental practice largely relegated to research laboratories and academia.

Digital analysis of dental images must be taken into account, not only when information related to dental shade needs to be transferred from the dentist to the dental technician, in order to reproduce the optical properties of dental structures using esthetic dental materials, but also when color parameters need to be recorded in order to monitor the changes in dental shade generated by some extrinsic factors (for instance, tooth staining or dental bleaching). The use of commercial digital cameras for accurate color capture is advantageous, but in order to be relevant to clinical research color difference parameters must be defined [12]. Digital methods of color analysis have become more widespread lately, their usage being extended into dental research, mainly in order to follow the results of a treatment which involves the change of dental shade [8].

The development of easy to use open source software for dental color matching, aimed to generate predictable results, is likely to improve the performances in color selection for both clinicians and dental technicians.

2. Program functions

In this section the main functionalities of the application are described.

The first category of functionalities that must be performed by the application is related to the use of images. The functionalities are the loading, saving, clearing of images and color key generation corresponding to the 26 shade tabs used.

The second functionalities category is related to calibration (see Figure 1. level 1 – Calibration). This functionalities category is important due to the fact that cameras when taking pictures alter the real colors. The calibration functionalities category consists of two different calibration types: calibration using shade tabs and calibration using 18% Grey Card.

The third functionalities category refers to the way in which the application's analyzed area is specified (see Figure 1, level 3 – Study area). The area may be specified either automatically or manually by the user. From the analyzed area the application must be able to exclude color anomalies, such as those created by flash light reflections.

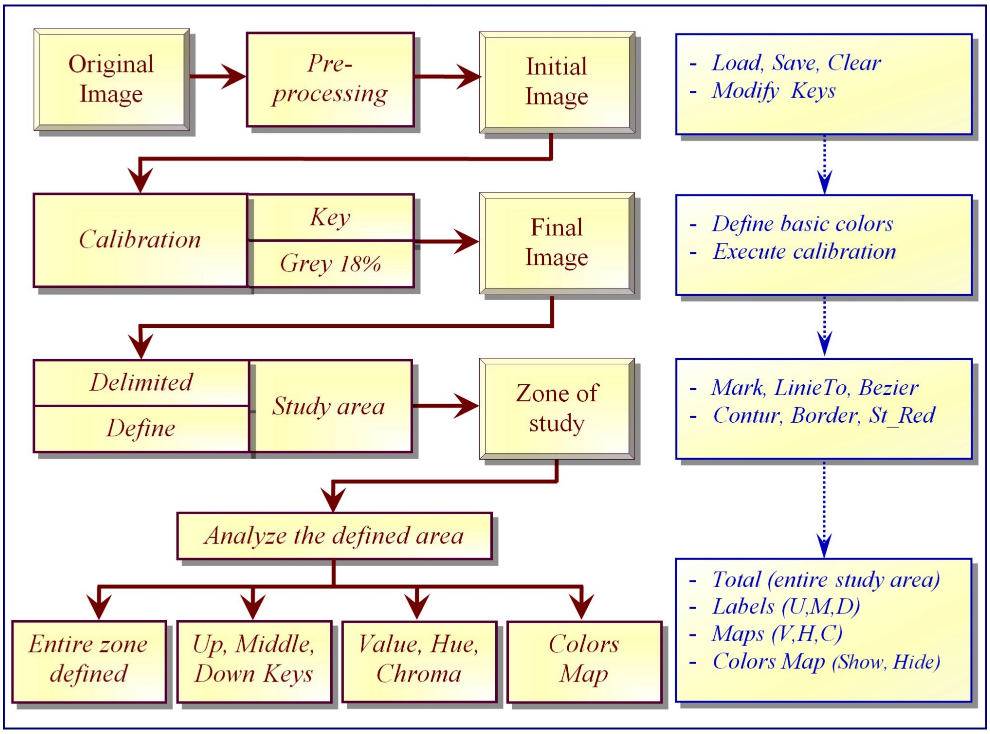


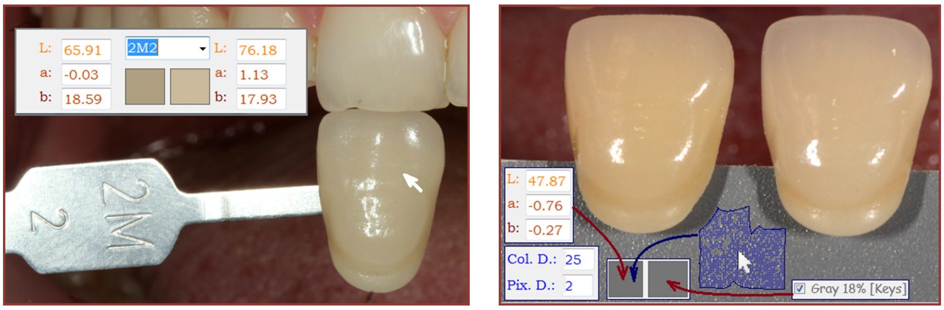
Figure 1. Color analysis features and steps

The final functionalities category is related to the application's results. The application needs to have two color analysis options: a global color analysis for the entire tooth area and a tooth zone analysis, corresponding to the cervical, middle and incisal areas in which the tooth contour was divided.

3. Implementation

The digital camera alters the colors which can lead to a wrong choice of color keys. For this reason, image calibration (the second functionality category described in Section 2 "Program functions") must be performed before proceeding to the proper analysis of the tooth's color (see Figure 1). Before color study can be performed, a necessary step is the determination of the image area corresponding to a tooth. Color analysis ignores undesirable areas (reflection or transparency areas) and computes the color search key which will be used from then on.

The first processing step performed on the dental image is color calibration (see Figure 1), performed in order to improve the realism of the image (see [4]). A first possible method is based on knowledge of a color key contained by the image. In practice, two colors are defined: the initial color of the base area of the image, denoted by C_{Init} in equation (1), computed as an average of the area's colors, and the final color associated with the color search key used, denoted by C_{Final} in equation (1) (see Figure 2a). The application user specifies the center of the initial area and is able to modify the implicit area parameters (the pixel network density as well as the color threshold used in computing the borders of the area that will be used to compute the color average of the area). The color search key used for calibration will be specified by selecting it from a list.



a) Using 2M2 Key b) Using 18% Grey paper

Figure 2. *Initial* and *final* calibration colors definition

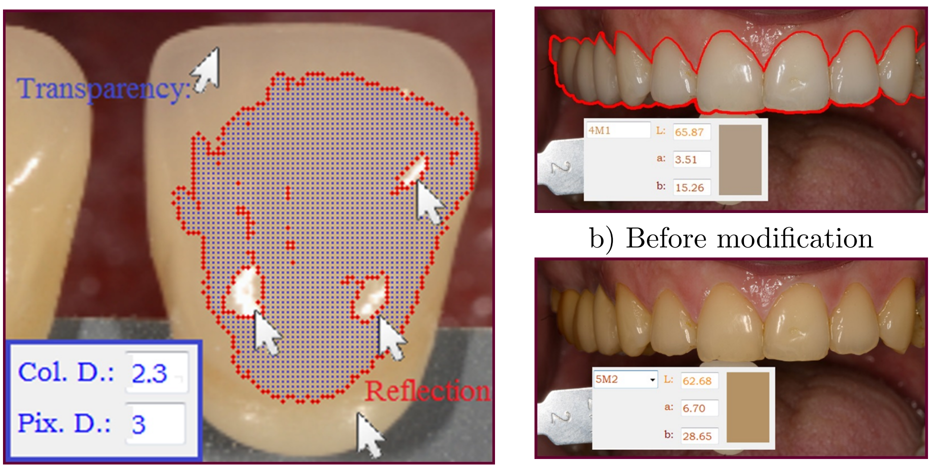
Modifying image colors will only be performed after a preprocessing stage that makes sure that the color template is in correspondence to the real color. The transformation, performed on each color component (red, green and blue) C, is given by the following formulae:

$$C' = \begin{cases} C * C_{Final}/C_{Init} & \text{if} \quad C * C_{Final}/C_{Init} \leq 255 \\ 255 & \text{if} \quad C * C_{Final}/C_{Init} > 255, \end{cases} \tag{1}$$

where C_{Init} and C_{Final} denote the initial, respectively the final calibration colors.

The second implemented method makes use of an object in the image whose color is known and fixed. An 18% gray card made of paper for which the real values $(118, 118, 118)$, in the red green blue (RGB) color space, are known was used. The formulae used in the transformations performed by this method are the same ones used by the first described method (see Equation 1). The definition area of the initial color portrayed as blue in Figure 2b is specified by the application's user using the mouse cursor directly on the image in order to select the starting pixel coordinates. The user is also able to modify the implicit values for the accepted color distance and for the distance between pixels. The final color obtained after calibration is Grey 18%. Testing has determined that the results obtained by this calibration method are much poorer than those obtained with the first calibration method described. This may be due to the fact that the 18% grey color is not present in the dental color subspace, whereas the final color obtained using the first calibration method is much closer to real teeth colors. Nevertheless, this calibration method is useful due to its significant benefits in automatic calibration. Regardless of the calibration method used, the colors obtained after calibration are much closer to the real colors than the uncalibrated image colors were.

The next processing step consists in the determination of the studied area (the third functionality category described in section 2 "Program functions") where color analysis will be performed. The distance metric ΔE^*_{ab} between two colors is compared to the color acceptability threshold (which usually has a value around 2.5) and if the distance is greater than the threshold the colors are considered distinct, otherwise they are considered to be similar (see Figures 3a and 3b, where the threshold is denoted by "Col. D"). This threshold has an implicitly defined value in the application but it can also be modified by the user.



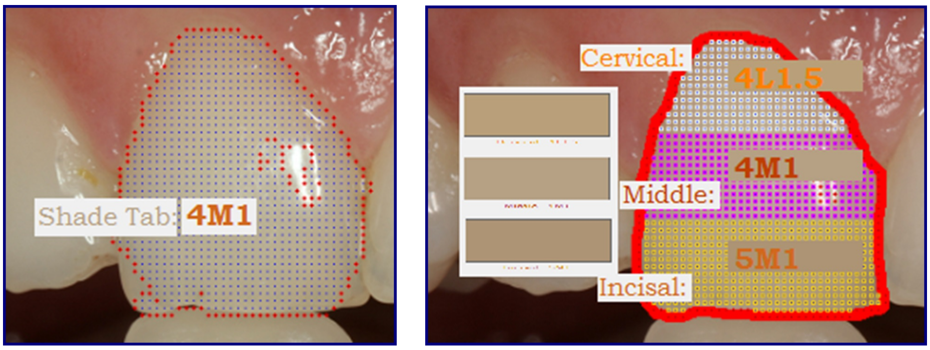
b) Before modification

a) Marking studied area c) After modification

Figure 3. Contur determination

If a smaller area is desired the user has at his disposal several options for defining the tooth's border directly on the image using pixels, lines or curves (*Mark*, *LineTo* or *Bezier*). The algorithms used for marking the studied area (*Contour*, *Border*, *St_Red*) are filling algorithms (*FloodFill*) they are non-recursive due to the fact that recursive variants were discovered to give much poorer results on large areas (such as those in Figure 3b and 3c). The algorithms are adapted to the application's functionalities and after the determination of the studied area, the color spots, present due to reflection or transparency, are excluded (see [5], [6]).

The result can be given by the average taking into account the entire marked area or only the three interest areas (see Figure 4a). In order to obtain the shade tab for the entire area defined, the average color will be compared with the previously determined color key pattern (standard palette – *banana* in the color space that represents tooth color subspace), and the result will be given as the closest color code as is used in dentistry (see [9]). Tooth color is given by light reflection that passes through the enamel and is reflected from the adjacent dentin layer. It presents an uneven color distribution on the tooth surface: the cervical area (the area next to the gingiva) is usually more saturated and opaque; the middle area presents a more even color distribution but colored texture can also be present at this level; the incisal area contains more thin enamel and no dentin layer, with a high degree of translucency. In the images this areas will appear black, because of the translucency. For the three interest areas (the *cervical*, *middle* and *incisal* areas) the average colors are computed, then for each the corresponding shade tab is computed and for each of them the code and hue is displayed (as it can be seen in Figure 4b).



a) Total – for entire zone b) Labels – cervical/middle/incisal

Figure 4. Shade tab

The obtained results are expressed in Vita Pan 3D Master shade guide. It is the most widely used shade guideline, containing 26 shade tabs, evenly distributed in dental color space [7]. Shade tab code (e.g. 2M1) are displayed by the program on a label placed on the tooth surface in the middle area, for the global analysis mode, or by three labels, each in its corresponding area, for tooth zone analysis mode. When a color of the dental surface is selected, an exact match of the shade tab is never possible. It will always be a color difference between the selected dental color and standard shade tabs. The software calculates ΔE^*_{ab} values between the L^*, a^*, b^* values measured on the digital image and shade tabs corresponding parameters (already implemented in the program). The final result is the shade tab that generates the lowest ΔE^*_{ab}.

When studying the resulting colors (hues) the user has the possibility to study the hue difference on the surface of the tooth on each of the coordinate of the HSB color space (*Hue*, *Saturation*, *Brightness* alternatively called HSV: *Hue*, *Saturation*, *Value* [1]) as it can be seen in Figure 5.

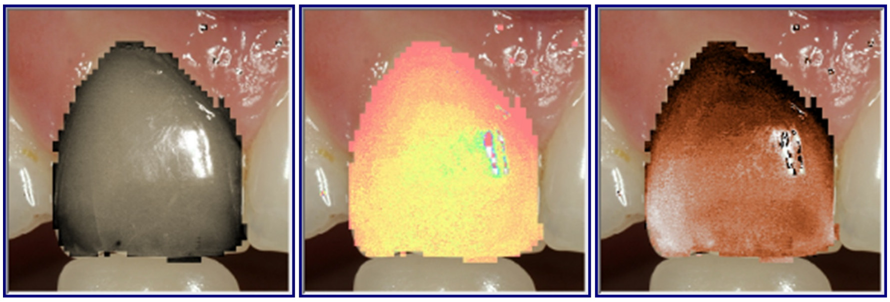


Figure 5. HSB coordinate color view

A tooth color map is also displayed. In order to notice the hue differences the colors will be codified (falsely colored) and the most frequent keys (i.e. the first 11 keys) will be displayed in the legend (see Figure 6). The other colors, that are those with low frequencies, are represented using the white color (*Other*).

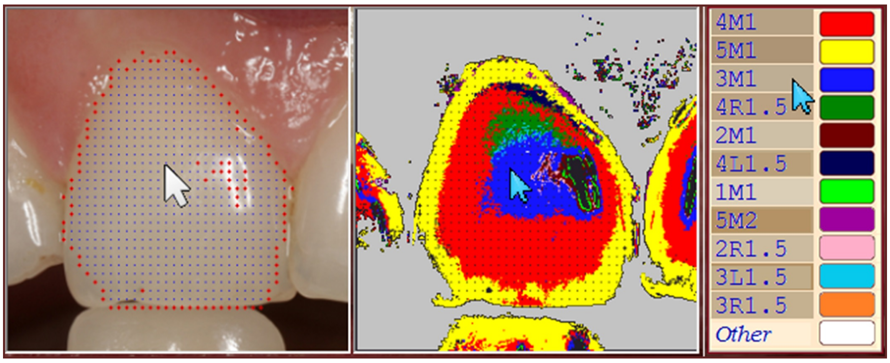


Figure 6. Tooth Color Map

4. Conclusions and further work

Color matching in dentistry is a complex process, which can generate errors, regardless of the method involved in shade selection (either visual or instrumental).

An experimental software for color selection was developed in the presented research. The program was able to match the shade tab colors, from calibrated digital images.

An experimental study was made; testing the accuracy of the program in measuring shade tabs color. Digital images of shade tabs were taken, and colors were match using the software.

The program was able to match the shade tab colors; the statistics indicates good accuracy when the results were presented in Vita 3D Master codification. A very strong correlations of the results were obtained Spearman's rank correlation = 0.914 ($p < 0.001$).

However, 19.23% of ΔE^*_{ab} values obtained were above the reference value of 3.2.

Further in vitro and in vivo evaluation of the program needs to be done in order to be used in routine clinical color selection. A tooth is usually polychromatic multiple colors can be found at the same time in different areas.

Further improvements of the program are indicated in order to be used for clinical color matching.

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Babeş-Bolyai University
Faculty of Mathematics and Informatics, Department of Informatics
Cluj-Napoca, Romania
E-mail address: per@cs.ubbcluj.ro

Babeş-Bolyai University
Faculty of Mathematics and Informatics, Department of Informatics
Cluj-Napoca, Romania
E-mail address: vcioban@cs.ubbcluj.ro

2014 Graduated Technical University of Cluj-Napoca
Faculty of Automatic Control and Computer Science
Cluj-Napoca, Romania
E-mail address: ghiran_alex_cluj@yahoo.com

University of Medicine and Pharmacy "Iuliu Haţieganu" Cluj-Napoca
Faculty of Dental Medicine, Department of Prosthodontics
Cluj-Napoca, Romania
E-mail address: ddudea@umfcluj.ro

University of Medicine and Pharmacy "Iuliu Haţieganu" Cluj-Napoca
Faculty of Dental Medicine, Department of Prosthodontics
Cluj-Napoca, Romania
E-mail address: bogdanculic@yahoo.com