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A Software Application to Detect Dental Color

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Abstract
Choosing dental color for missing teeth or tooth reconstruction is an important step and it usually raises difficulties for dentists due to a significant amount of subjective factors that can influence the color selection. Dental reconstruction presumes the combination between dentistry and chromatics, thus implying important challenges. *Purpose:* The aim of this study was to develop and implement a software application for detecting dental color to come to the aid of dentists and largely to remove the inherent subjectiveness of the human vision. *Basic Methods:* The implemented application was named Color Detection and the application's source code is written using the C++ language. During application development, for creating the GUI (graphical user interface) the wxWidgets 2.8 library it was used. *Results:* The application displays the average color of the selected area of interest, the reference color from the key collection existent in the program and also the degree of similarity between the original (the selected area of interest) and the nearest reference key. This degree of similarity is expressed as a percentage. *Conclusions:* The Color Detection Program, by eliminating the subjectivity inherent to human sight, can help the dentist to select an appropriate dental color with precision.

Keywords: Dental coloring; Dental prosthesis; Computer software applications; Dental general practice

Introduction

Choosing dental color for missing teeth or tooth reconstruction is an important step and it usually raises difficulties for dentists due to a big amount of subjective factors that can influence the color selection [1]. Dental reconstruction involves a combination between dentistry and chromatics, thus implying important challenges [2]. The reconstructed teeth must correspond functionally and also from an esthetic point of view. When it comes to color the dentist should take into consideration the tooth position and the restorative material's texture [2]. In order to balance the

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science of dentistry and the art of creating beautiful smiles, this profession must continue to advance in the field of esthetic restorations. About 50% of the restorations are the result of a failure in terms of choosing the precise shades [3].

Increasing patients' interest and exigency regarding esthetic dentistry has led to a significant increase in the interest for research on dental coloristic [4]. Although progress has been made by improving the color guides and the availability of technologized systems for color identification, selecting colors still remains one of the most difficult tasks in clinical practice [5-7].

Color selection is most frequently made by using a color key [8], this technique being influenced by the light source, tooth, inclusiding textures, layers, environment and receptor (the eye) [9]. The technologized systems, by not being influenced by these parameters, may allow an accurate color selection, although they do present advantages and disadvantages [10-12].In dental practice, the most used devices for clinical shade-matching are spectrophotometers and colorimeters [4]. A spectrophotometer usually divides and measures the amount of light reflected by an object at multiple intervals along the visual spectrum and also provides a secondary data analysis. A colorimeter is difficult to design and if the technology is not precise the result would be a reduction in precision of color determination. Also due to the fact that these devices do not register the spectral reflectance, are less accurate in comparison with a spectrophotometer [4].

It should be noted that, although the extensive use of computers in dentistry led to the emergence of a new branch in medical informatics, dentistry informatics (dental medical informatics) [13], the progresses in the computing domain were not necessarily followed by progress in the field of choosing and matching of dental colors. Thus, it is significant that, in the twenty-first century and in full digital area/era? , in the majority of dental offices the choice of dental colors is still made based on color keys or palettes, a process which involves a highly subjective factor, the human sight.

Color determination quickly evolves towards a more objective standard. The significance of choosing the right color in esthetic dentistry is very important. In case of choosing an incorrect color due to the material's structure and other aspects, the desired result will not be achieved.

The aim of this study was to develop and implement a software application for detecting dental color in order to come to the aid of dentists and largely to remove the inherent subjectivity of the human sight.

Material and Method

An application named Color Detection has been developed in collaboration with staff from the Medical Informatics and Biostatistics discipline, from the University of Medicine and Pharmacy of Tîrgu Mureş. The application's source code is written using the C++ language. During application development, for creating the GUI (graphical user interface) the wxWidgets 2.8 library it was used.

Color Detection allows taking pictures in JPEG format asynchronously captured (with digital cameras) and its use in real-time along with digital intraoral cameras. The application also allows the establishment of a particular color key specific for each practician, either by starting from color keys created by consecrated brands, either from their own case records. The algorithm used for the implementation is illustrated in the Figure 1.

Any interested area of the dental arch can be selected via a simple and easy-to-learn procedure. The proposed application works with additive color patterns (RGB, sRGB) and in case of applications for dental technology's field, it can be easily adjusted to work with subtractive models of color (based on pigments) such as the CMYK model. It also has an extremely intuitive interface, which makes it easy to operate; furthermore, it can be used by those with limited knowledge in (the field of) Informatics. The interface of the application was created to allow displaying the color in hexadecimal format (according to the RGB model of the reference color from color palettes created by us and the percentage of color's similitude) as well as displaying the original and the reference for easy visual identification.

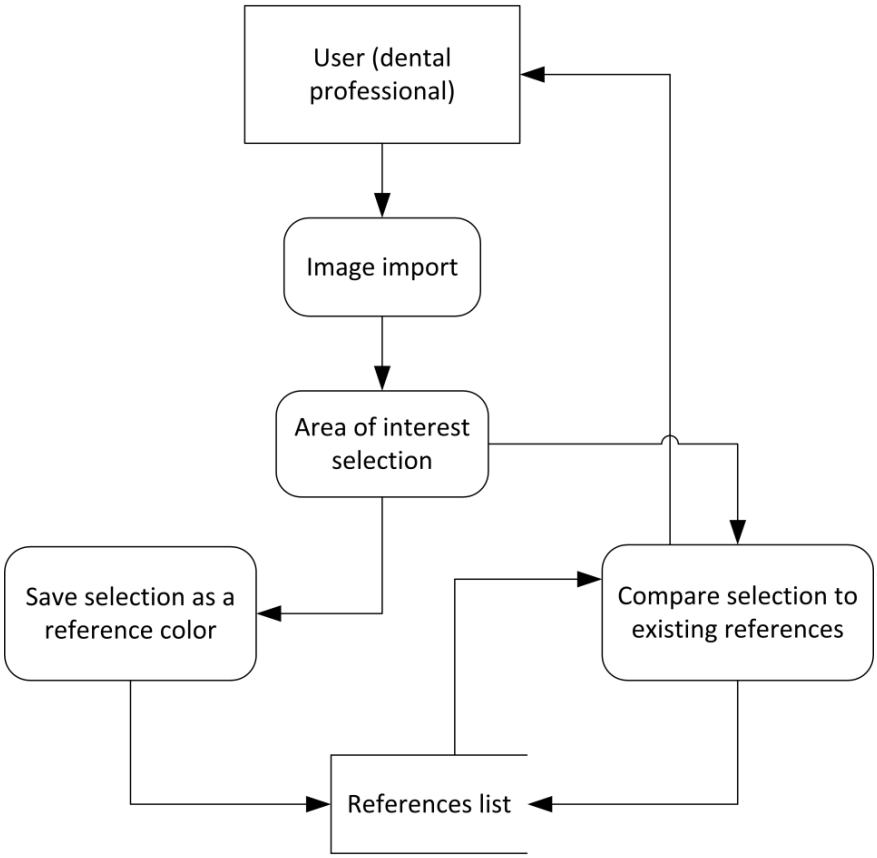

Figure 1. Application data flow diagram

Results

The image's import area, at the bottom of application start screen comprises of one import button and a display area of the access path to the current used file, in order to allow the user to know exactly which image is currently processing.

The image's display area also includes selection zone of the areas of interest for color determination.

Selecting areas of interest (Figure 2) is extremely simple and intuitive, using the left and right click buttons of the mouse, as follows: with the left click button the areas of interest are selected and those selected by accident will be cancelled with the right click button of the mouse on the blue squares which mark the interested areas.

At the bottom of the application start screen there is a small area which contains a "browse" button and the path to the selected file. The user always knows which file is opened for image processing.

The image display area also includes the selection zone of the areas of interest for color determination.

The selection of the areas of interest may be multiple and the program also allows the easy correction of the errors of interested areas' selection by adding or removing new areas to/from the selected areas.

The references' saving area is one of the most important areas of the program and it is comprised of two buttons: one button to reset the current selection, allowing resumption of work on the same image, eventually on another area of interest, and another saving button as reference to the area of interest previously selected.

This functionality allows the construction of collection of color keys/palettes at the user's choice, who can develop his/her own color key without depending on the palettes offered by random brands.

Moreover, collections of existing color palettes can be combined using this technique in its own set of dental color.

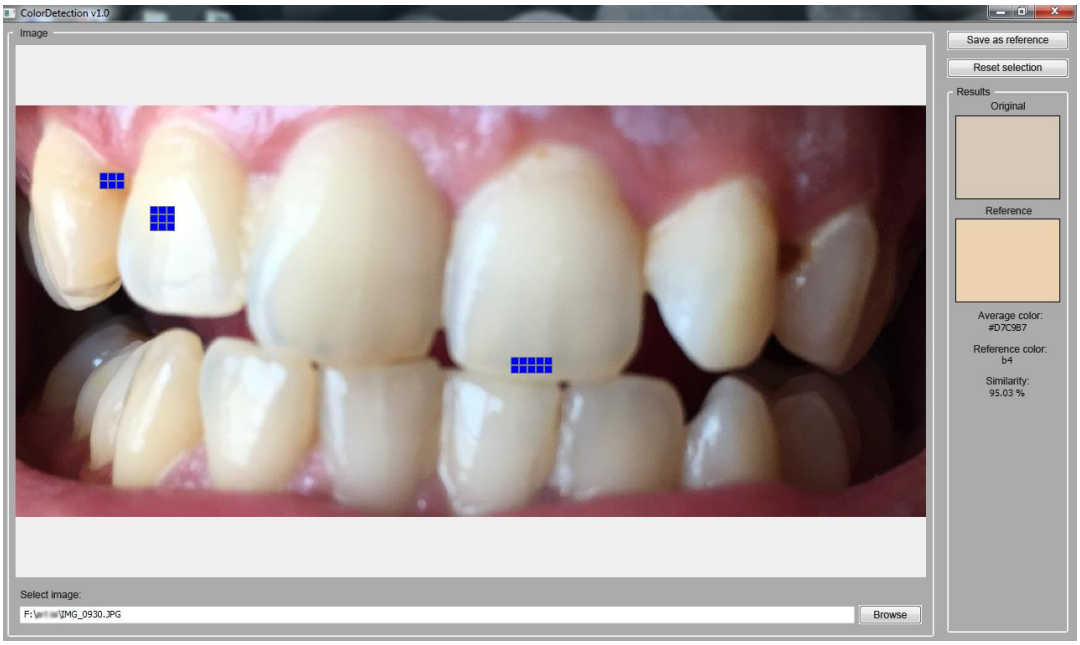

Figure 2. Selecting areas of interest

For the storage of information related to dental keys' palettes the use of XML files (extended markup language) has been chosen. These files contain the key collection of a certain user, information related to the color code in RGB space (expressed in hexadecimal system) and the name chosen by the user for the respective color key (Figure 3 and 4).

```
<?xml version="1.0"?>
- <references>
  - <reference>
      <name>a1</name>
      <color>#F6EFE3</color>
    </reference>
  - <reference>
      <name>a2</name>
      <color>#F5EAD5</color>
    </reference>
  - <reference>
      <name>b1</name>
      <color>#F4E6CF</color>
    </reference>
  - <reference>
      <name>b2</name>
      <color>#F1DEC1</color>
    </reference>
  - <reference>
      <name>b3</name>
      <color>#EFD8B8</color>
    </reference>
  - <reference>
      <name>b4</name>
      <color>#EDD2B0</color>
    </reference>
</references>
```

Figure 3. Coding the color keys in XML format

The results' display area (Figure 2) of the determination and the match evaluation is divided in two smaller areas. The inferior zone, displaying: the average color of the selected area of interest, expressed in hexadecimal code according to the RGB color space; the reference color from the key collection existent in the program according to the coding chosen by the user or by the person who generated the set of keys and transmitted it in XML format to the program's user; the degree of similarity between the original (the selected area of interest) and the nearest reference key. This value is expressed as a percentage.

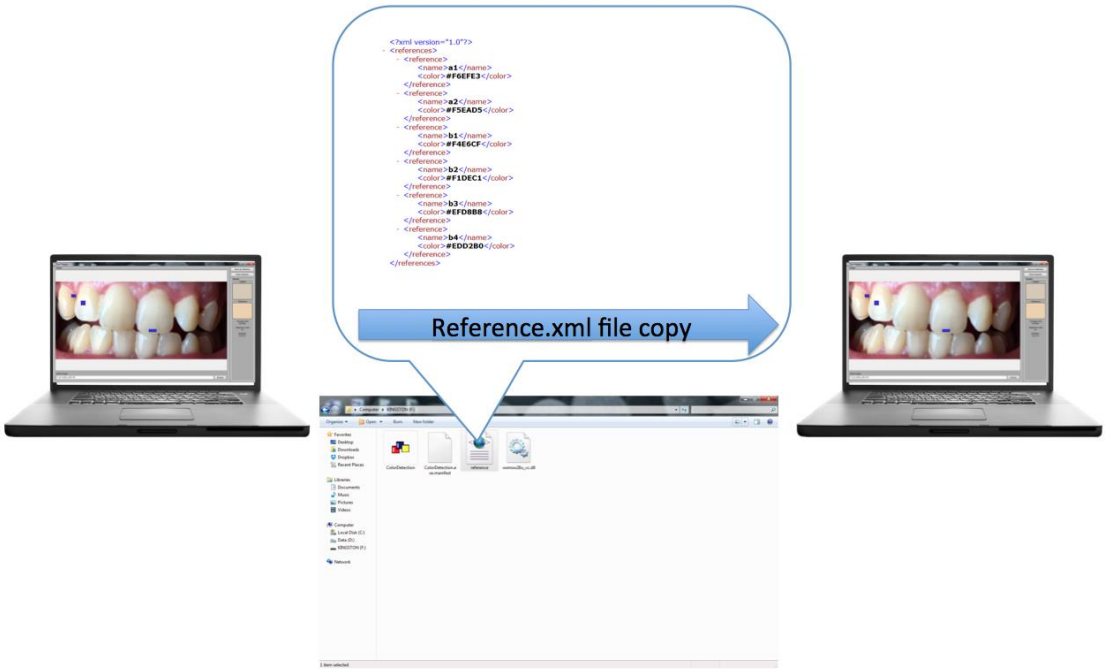

Figure 4. Transfer color keys from a computer system to another

The superior area of results' display shows visually the original's color (the selected area of interest), respectively the color of the reference key as the closest similarity. In this way, for a degree of similarity of over 90%, the user will not perceive any difference between the two colors, while at a lower degree of similarity; the differences become visible for the human eye.

Discussion

Through the functionalities and the ease of use, the developed program can be used by dentists of all ages and it can compete with other assistance computer's solutions to matching colors in dentistry. The program solves most of the problems related to human visual subjectivity.

A major problem in dental images acquisition is represented by illumination, whether it is about environmental light or scialitic lamps' light. For this reason, the acquisition of dental images for this purpose should take place in a light setting that is similar to daylight. An efficient yet affordable solution would be the use of a digital intraoral camera equipped with circular illumination light of six lights of 5600K. The model used for testing (I-Cam wireless intraoral camera, model SS-CS001) is one of the cheapest models available on the market and yet it has some high performance features. The most important one is that it provides a permanent illumination on the photographed surface with a similar light to daylight (5600K).

The process of acquisition, processing and matching colors involves the use of a digital intraoral camera which can be wireless or with USB connection. The next step is the calibration of the camera for the ICC color profile, sRGB. Afterwards, the calibration of the computer's monitor (desktop, laptop for the sRGB color model) is effectuated by using the appropriate sRGB profile,

followed by the image's acquisition and its saving (in JPEG format) and its import into the ColorDetection application.

During the program's development the creation of a simpler, yet effective user interface was permanently considered, in order to facilitate its use by less trained people in IT and computers.

Starting from these premises the use of cryptic or complex menus was dismissed and we structured the user interface (UI) to be composed of specific areas, each having well defined functions.

The technologized systems of color identification are based on digital cameras, spectrophotometers and colorimeters. Most of the available video cameras use the amount of red, green and blue to form the image; these devices are generally called "RGB" cameras. The inherent problem with these systems is that they cannot control some of the variable keys associated with the exact color determination. Usually, the color is created from RGB data using various hypotheses regarding the photo camera and also by using reference materials in the captured images. The devices based on the spectrophotometer measure the luminous radiation's absorption. A spectrophotometer measures the relative reflectance or transmittance of light from a sample of color to many points of the visible spectrum [14-15]. At this time there are on the market multiple commercial products of spectrophotometers (Crystaleye, Olympus, Tokyo, Japan [8]; Vita Easyshade Compact, Vita Zahnfabrik, Bad Säckingen, Germany; Shade-X, X-Rite, Grandville, MI; SpectroShade Micro, MHT Optic Research, Niederhasli, Switzerland [4]) but there are some disadvantages as the high cost, or the fact that they are usually calibrated for the color keys of certain producers.

The colorimeters are designed to directly measure color as being perceived by the human eye. Their projection is difficult and if there is no precise technology, the result will be a reduction in accuracy in comparison with a spectrophotometer [16].

Along with the progress of information technology and the appearance of the Dentistry Informatics field, a series of software solutions have been developed in the area of color matching. One such application is ClearMatch, developed by Clarity Dental Corporation, which uses high resolution digital images and compares shades of the entire surface of the tooth with reference shades [4, 17]. Although it is a relatively easy to use program, it has a fairly high cost and it does not allow the establishment of a personal color key for the specialists.

The proposed program is meant to help dentists by offering an interactive interface, ease of installation and use and also a low cost. Due to the fact that the program is based on LGPL licensed libraries (Lesser General Public License), it leads to the application's inclusion in the "free software" category, the dentist having to invest only for an intraoral camera.

Moreover, the program can be modified for the use of the subtractive color pattern (the pattern based on pigments) for its application in a dental technology office. The required steps are similar to those set in the purchase model in real time, with small differences .The dental technician will also use an intraoral camera as mentioned above, for image acquisition of the prosthetic appliance, in this way providing the permanent illumination (without sharp reflections) with similar light to daylight, fact which will eliminate the possible artifacts that occur in case of photographing a prosthetic appliance. The match's results will be expressed in both RGB colors and CMYK colors. Such an approach would allow: setting up a library of pigments codes used in dental technology, each pigment being uniquely analyzed by the CMYK code, the extremely precise combination of the pigments used in dental technology by converting the natural teeth' image from the RGB mode to CMYK mode, and providing a recipe for combining pigments by the dental technician.

Conclusions

The choice of colors in dentistry is an extremely difficult task, so the Color Detection Program, by eliminating the subjectivity inherent to human sight, can help the dentist to select a dental color as precise as possible.

The program allows the selection of more than one area of interest for color determination, useful when multiple teeth are to be reconstructed.

The application enables the user to reset a current selection and resume work on the same image, and also to save an area of interest as reference. This function permits the construction of color keys.

Conflict of Interest

The authors declare that they have no conflict of interest.

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