

# Uncertainties in Tooth Colour Measurement using Digital Camera

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## Abstract

In this study, a tooth-imaging system, in which there is a digital camera used as the acquisition device, was developed to measure tooth colour and various uncertainties in the measurement were investigated, including validity of the LED light source (drift over time and colour rendering ability), accuracy and precision of the characterisation model, influence of variation in the distance from subjects to camera in tooth-imaging trials and drying effects of teeth during image capture. This research was to establish the major source of error in tooth-imaging trials and also to reduce measuring errors as much as possible to optimize the performance of the tooth-imaging system in practical use.

## Introduction

The colour of teeth probably constitutes one of the most important parts of our first impression of someone. Whitening teeth for aesthetic purposes is currently fashionable. In addition, prosthodontic reconstruction requires that the porcelain matches a patient's natural teeth or existing porcelain teeth. These are examples of situations that have raised the need for tooth colour measurement in the field of dentistry in recent years.

The two general methods commonly used to analyse the natural colour of teeth are visual comparison and instrumental measurement. In dentistry, visual colour determination is based on the comparison of the remaining teeth in the patient with commercially available shade guides as a colour standard. Because of the inconsistency among dentists in matching the tooth colour when using this method,<sup>1,2</sup> instrumental approaches have been investigated in laboratory and clinical stages to try to get more reliable measurement. A spectrophotometer or spectroradiometer is commonly employed in measuring tooth colour as an alternative to visual assessment.<sup>3</sup> Recently, with the development of digital photography, a different method that uses a digital camera for colorimetry of human teeth was proposed.<sup>4,5</sup>

Photography has been used for many years for different purposes in dentistry. It provides the dentist with information about teeth such as surface texture, shape and colour distribution. As tooth whitening has become a popular and routine dental procedure, the measurement of tooth colour, especially for the evaluation of the efficacy of the tooth-whitening products, is becoming increasingly important. The increasing interest in tooth-whitening raises the need for digital photography to record and assess the colour of teeth in clinical whitening trials. The dentistry interest is in the

accuracy and consistency of tooth-colour rendering. The term "uncertainty" is used to denote the dispersion of values that could be attributed to a measurement result. A typical tooth-imaging system usually consists of a light source and a digital camera. In clinical tooth-imaging trials, it also involves real patients. Understanding the sources and magnitudes of uncertainty in tooth-colour imaging is of high scientific and industrial importance.

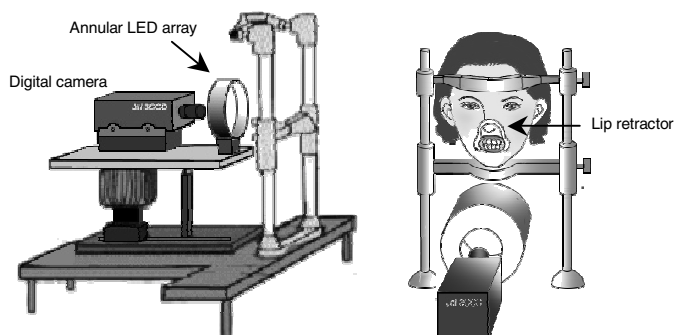
The task of this study was to investigate the uncertainties in tooth-colour measurement based on a tooth-imaging system. The sources of uncertainty in tooth-colour measurement using digital camera can be divided into three main categories.

- Uncertainty due to light source (temporal variability and colour rendering ability);
- Uncertainty due to digital camera (accuracy and precision of tooth-colour measurement);
- Uncertainty due to patients in clinical trials (measuring-distance variation and drying effects of teeth in the image-capture process).

## Experimental

### The Instrument

This research is based on a tooth-imaging system<sup>6</sup> which was developed to measure tooth colour in teeth-whitening trials. Figure 1 shows the schematic of the tooth-imaging system with the light baffle removed for clarity.



**Figure 1** Schematic of the imaging system with the light baffle removed for clarity. The imaging system comprised of a digital camera (Jai 3CCD) mounted in a fixed position relative to the subject. The light source was provided by an annular LED array within a light baffle to reduce the intrusion of ambient lighting. A polarising lens was situated in front of camera lens to minimize any specular reflection from the teeth. The camera provides live videos through a frame-grabber card (Flashpoint 3D 4xl card, Integral

Technologies, Inc.) connected to a computer. Patients use a lip retractor to expose their teeth in the teeth-imaging experiments.

### The Uncertainties

There are many sources of uncertainties in real clinical tooth-imaging trials. Besides the uncertainties due to the instrument, measuring errors caused by patients are also involved in. Several experiments were designed and conducted to investigate these errors.

The primary light source used in the tooth-imaging system was an annular array of Light Emitting Diodes (LEDs). The mechanism of light production in the LED arises from the phenomenon of electroluminescence. The intensity of the LED can be controlled by adjusting the input voltage from the power supply. A tele-spectroradiometer (TSR) was used to measure the radiance of a white tile located at the subject's position in the system. The temporal repeatability of the light source was found to be poor, the variation was over 10 % during a three-week measurement. In order to get a more stable light source, the intensity of the LED was controlled with the aid of a program written in MATLAB to ensure that the output RGB from the live video of the white tile is nearly the same over time. By this method, the repeatability of the system was improved dramatically. As this repeatability is a combination of the repeatability of the light source and the digital camera, in this paper it was reported in the performance test of the characterization of the system.

Colour rendering index (CRI) is a unit of measure that defines how well colors are rendered by different illumination conditions in comparison to a standard. In order to test the ability of the LED light source to reproduce various colors when comparing with the CIE D65, a method devised by CIE based on measuring eight sample colours was used to calculate the index. The light source was found to be 78 CRI rating, which could be considered to be not poor for colour rendering compared with the daylight D65.

One of the most important parts of measuring tooth colour using digital camera is characterization, which is to establish the relationship between the camera RGB space and the device-independent representation (XYZ). High accuracy and precision are two targets in the procedure of building the characterisation model. The characterization procedure of the Jai camera consisted of three steps: linearization, uniformity correction and polynomial modeling. After evaluating three polynomial transforms (1<sup>st</sup>-order, 2<sup>nd</sup>-order and 3<sup>rd</sup>-order), a camera characterization model was constructed based upon a linear transform, the coefficients of which were optimized based on a set of reference porcelain teeth samples (the Vita 3D shade guide).

In practical dental imaging trials, although the positions of the camera and the holder for patients are approximately fixed, the head of patients could easily go a little forward or backward, which could makes the image lighter or darker due to the different distances. Whether this effect is significant to the system consistency is unknown. In order to find out the effect of the distance uncertainty in the dental imaging system, images of a

tooth sample (which is in the middle of the rank of the teeth from 3D shade guide) on 25 different positions with 1mm interval in the lens-axes direction. The middle position is the one on the camera focus plan, which is supposed to be the position for taking standard image in tooth-image trials.

Another problem in clinical tooth-imaging is the effect of patients' teeth drying over time during trials. In order to investigate the influence of teeth drying, an experiment was carried out to take images of teeth before and after drying. Four images for each of 10 patients were taken with 1-minute intervals over about 3 minutes. The first image was taken immediately after the patients put their heads on the subject holder (with wet teeth). The four images were designed to show the changes in colour of teeth on different drying levels.

### Results and Discussion

For instrumental uncertainties, since temporal variation caused by light source was minimized by programming control and spatial non-uniformity was corrected by one additional stage in characterization, the main task left is to test the performance of the characterization model of the system. The accuracy of the system illustrates how far away from the real (or target) XYZ values are the XYZ values predicted by the system. It was found that the 3<sup>rd</sup>-order polynomial model has the best performance for the training set (26 teeth from the 3D shade guide), with an average colour difference about  $0.69 \Delta E_{ab}^*$  unit. Whereas for the test set, Vita Classical shade guide (16 teeth), the 1<sup>st</sup> and 2<sup>nd</sup>-order polynomial models appear to fit the data better, with average colour differences less than  $3 \Delta E_{ab}^*$  unit.

The repeatability (or precision) of the system shows how stable the tooth-colour reproduction is over time. The system was first calibrated (the intensity of the light source was set to give consistent results) and then the test set (Vita Classical shade guide, 16 teeth) was captured once per day over five days. The average colour difference of the five-days measurements compared with the overall mean value was found to be about  $0.80 \Delta E_{ab}^*$  unit for the porcelain teeth.

For testing the influence of distance variation, a test sample was moved forward and backward in 12 steps, with 1mm interval. The RGB values were grabbed and converted into  $L^*a^*b^*$  to investigate the perceptible difference. Generally, heads of patients move in a small range of about -1cm to 1cm, the percentage average camera RGB error was about 5%, after the nonlinear transform, the average colour difference in the -1cm to 1cm range was about  $0.44 \Delta E_{ab}^*$  unit.

Figure 2 summarizes the results of the teeth-drying test. It can be seen that drier teeth become darker and yellower than wet teeth. It may be caused by less specular refraction from the drier teeth and also the temperature of the teeth may increase after being under the high intensive light source for long time. Although there is an obvious trend of colour changes for teeth drying, actually, the changes are quite small within 3 minutes. With the time past,  $L^*$  and  $a^*$  values decrease about 1%,  $b^*$  value increases about 2%. The average colour difference within 3 minutes was about  $0.37 \Delta E_{ab}^*$  unit, with the maximum value of  $0.57 \Delta E_{ab}^*$  unit on the forth

capture. So when taking images, it may be prudent to ask patients to wet their teeth once per minute when waiting for the capture.

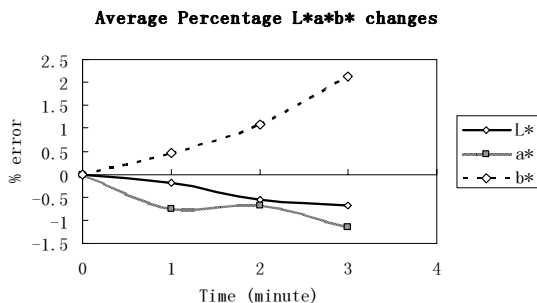


Figure 2 Colour changes in CIELAB space in the teeth drying test during 3 minutes.

### Conclusion

Figure 3 summarizes the overall uncertainty results in  $\Delta E^*_{ab}$  units. It can be clearly seen that the inaccuracy of the characterization model was the major source of error in tooth-colour measurement, whereas all the other uncertainties were lower than 1  $\Delta E^*_{ab}$  units. The accuracy of the system is essential in tooth-imaging, for most tooth-imaging trials; however, a reliable and repeatable imaging system is arguably even more important. It can be believed that the system was practically stable for the tooth imaging task, as colours within 1  $\Delta E^*_{ab}$  unit can hardly be distinguished by normal human perception.

Overall Uncertainties in Tooth-imaging

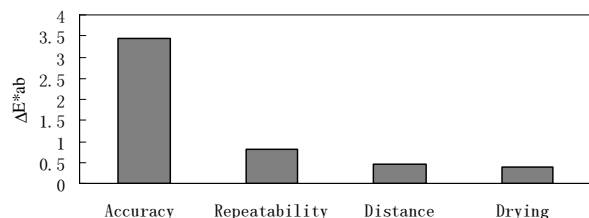


Figure 3 Overall uncertainties in tooth-imaging in CIE  $\Delta E^*_{ab}$  unit.

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### Author Biography

Wen Luo completed her BSc degree in Computer Science and Communication at Southwest Jiaotong University, China, in 2002, and then obtained her MSc degree in Colour Science from the Colour Imaging Institute at the University of Derby, UK, in 2003. She is currently working on her PhD project 'Assessment of Tooth Whiteness using Digital Camera' (sponsored by Colgate) under the supervision of Prof. Stephen Westland at the University of Leeds, UK.