Living Optics

Hyperspectral Imaging for Dental Shade Matching

Shade selection in dentistry

Accurate shade selection is a fundamental step in cosmetic dentistry. Correctly matching the shade of a restoration to the patient's natural teeth is essential for aesthetic outcomes and patient satisfaction, while poorly matched restorations may require costly rectification. Shade selection lis usually achieved by performing a visual comparison using a shade guide.

Practitioners face several challenges in making a successful assessment, including:

Lighting – the colour of a tooth is influenced by the spectrum of the light that illuminates it. The same tooth may appear different colours in different lighting conditions. Due to metamerism, a restoration that is well-matched under one illuminant may appear mis-matched under another.

Environment – the colour of other objects in the environment affects how the colour of the tooth is perceived.

Shade guide limitations – each shade guide system provides only a limited number of shades to choose from. There can be inconsistency between shade guides (even those of the same type) and they can degrade over time leading to inaccuracies. Practitioners are increasingly leveraging technological approaches to complement visual assessment, seeking quantitative shade measurements that can improve the efficiency and accuracy of shade-taking, and allow colour information to be readily documented and communicated. Hyper-spectral imaging is an under-explored technology with unique advantages for dental shade-taking applications.

Improving efficiency, accuracy and patient satisfaction with HSI

Hyperspectral imaging (HSI) can completely characterise the colour of a tooth by measuring its wavelength-dependent reflectance.

- Offers a quantitative measurement that removes human subjectivity and simplifies the communication of colour information between practitioners, technicians and patients.
- Provides a colour measurement that is independent of the lighting conditions under which the tooth is measured.
- Possible to simulate how the colour of a tooth & its restoration would be perceived under any other lighting condition, avoiding mis-matches due to metamerism.
- Records spectral information from hundreds of points across the image and enables mapping of colour variation across the surface of the tooth.

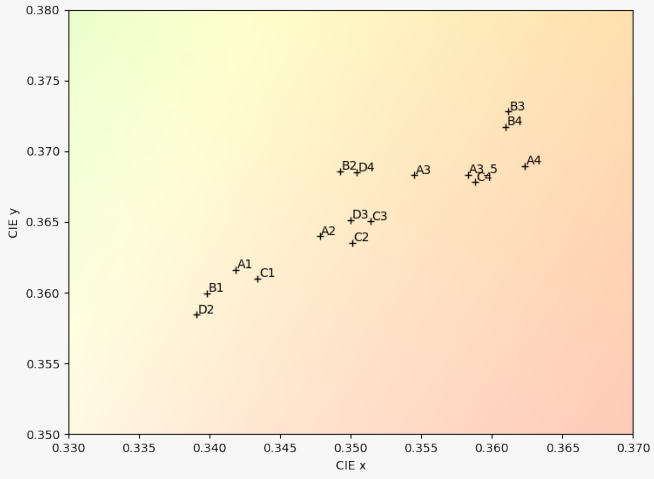
The Living Optics Advantage

Based on pioneering proprietary snapshot technology, the Living Optics camera is a portable system capable of real-time hyperspectral applications. The technology is based on a coded aperture and two co-aligned sensors, offering a 5 megapixel 'Scene View' image of the field of view, and 96 bands of 440- 900 nm spectral information, collected from over 4000 locations in the scene. The camera is paired with an NVIDIA Jetson AGX Orin, which provides the compute power necessary for real-time video analyses, such as live image segmentation and colour matching.

Quantifying tooth shade

To investigate tooth shade analysis with the Living Optics camera, hyperspectral data were acquired for each of the tabs of the VITA Classical shade guide. The spectral radiance data output by the camera was converted to reflectance by dividing by the spectral radiance of a white reference object (Spectralon tile) measured under the same illumination conditions.

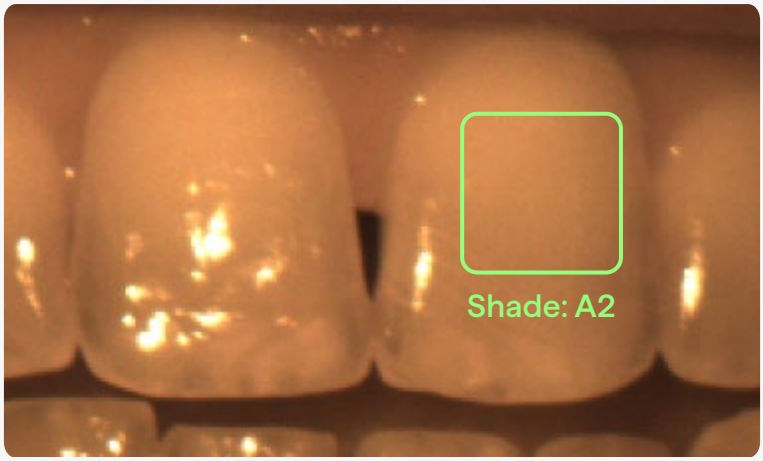
Once the reflectance spectrum was obtained, CIE (X, Y, Z) tristimulus values were computed. These were further transformed to CIE xy chromaticity coordinates for 2D representation:



CIE xy chromaticity coordinates for each of the shades in a VITA classical shade guide under D65 illumination, as measured by the Living Optics camera. To guide the eye, the background shading indicates the approximate RGB colour corresponding to each point in CIE xy space.

In vivo colour matching

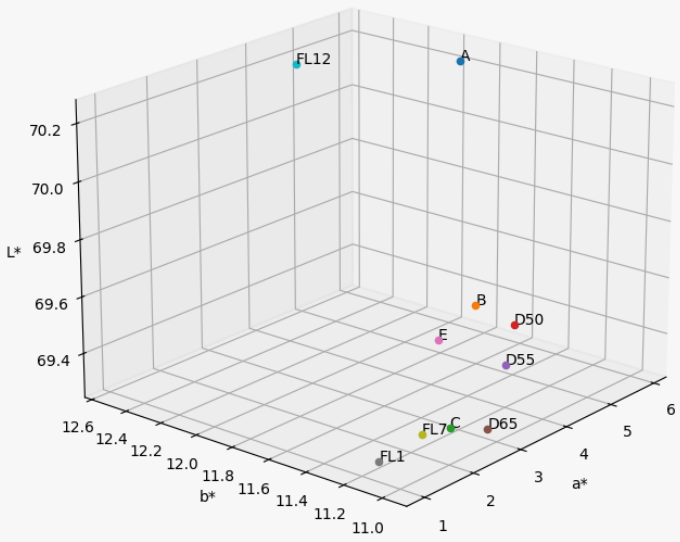
Colour differences are commonly described by the quantity ΔE_{76}, which is the Euclidean distance between two points in the CIE LAB colour space. To perform shade-matching, the measured tristimulus values for the VITA Classical shades were first transformed into CIE LAB coordinates and then compared with those obtained for an in vivo measurement of human teeth. ΔE values were calculated for the human tooth CIE LAB coordinates, with respect to each of the VITA Classical shades, with the smallest ΔE indicating the closest match.



Living Optics Scene View image of human tooth annotated with the best VITA Classical shade match as calculated for the rectangular region indicated in green.

Simulating lighting effects

Once the spectral reflectance properties of a tooth are characterised, it is possible to simulate the colour it will appear under any illuminant, given that illuminant's spectral power distribution:



Graph showing the CIE LAB coordinates of the same tooth under various CIE standard illuminants, calculated using Living Optics hyperspectral data.