PERiSCOPE: Personalized Color Profiles
A modern methodology for rendering colour in digital media displays

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Colour and colour perception are of great relevance for many scientific fields and constitute important aspects of the aesthetic appearance of most artwork. In art history, visual arts, media sciences and photography, colour is an important attribute for assessing and reviewing most objects. Virtual Research Environments, for example, allow scholars to access, compare, and discuss digital renderings of paintings, photographs, video and motion pictures. The quality of colour rendering of these digital objects is crucial for most analytical work because colour is one of the most important features that is communicated. We propose to revolutionize the current colour rendering methodologies on state-of-the art displays and printers, for better "true" colour management of digital still images, video, or motion pictures.

Since the early years of colour science, the 1931 CIE Standard Observer has been a major reference for colour reproduction (Guild, 1925, 1932; Wright, 1929). The CIE Standard Observer defines how we can quantify colours that we see in the linear XYZ, or the perception-based Lab colour space. There are, however, several disadvantages to the system, arising mainly from the inherent assumptions made during the (very controlled) colour matching experiments used to derive the colour-matching functions (MacDonald, 2015). Most significantly, the original approach describes only the average of the experimental results, while those results are based on a small group of test individuals, in this case, 49 British men. Since the original experiment does not address the physiology of an individual observer, it has several qualitative limitations that result in colour reproduction with limited accuracy.

Since the original Standard Observer experiment, several studies have been performed aiming to improve the original colour matching functions (CMFs). Stiles and Burch, in 1959, repeated the experiment this time with an increased viewing field of 10 degrees, from the 2 degrees used for the 1931 results (Stiles & Burch, 1959). More recently, in the '90s, groups critically analyzed the 1939 and 1959 results to derive more precise CMFs. This is the case with Stockman et al in 1999 (Stockman, Sharpe, & Fach, 1999), who were able to propose new spectral sensitivity functions for the S-cones (the eye's short-wavelength light receptor), both with their own experimental methods and by analyzing the existing functions. Meanwhile, individual differences in CMFs were estimated by North and Fairchild in 1993, this time by performing a small number of colour matching measurements and using a computational model to derive the CMFs (North & Fairchild, 1993a, 1993b). Investigations of individual variabilities in detecting colour among colour-normal individuals were performed in 2015 by Asano et al. and showed higher than expected interobserver variability (Asano, Fairchild, Blondé, & Morvan, 2015).

There are multiple studies that have been investigating the connection between colour perception and physiological (Abramov, Gordon, Feldman, & Chavarga, 2012a)(Abramov, Gordon, Feldman, & Chavarga, 2012b) and cultural (Collier, 1973; Merrifield, 1971)(Winawer et al., 2007)(Roberson, Davidoff, Davies, & Shapiro, 2006) differences, however the mechanisms that control the individual colour perception (i.e. the specific way that each person sees, understand and responds to colour) are not fully understood.

In this project, we plan to revisit the Standard Observer Experiment (SOE) and test its validity for different portions of the population. We will employ current technologies to develop and use a modern experimental setup based on LEDs and emphasize on these specific parameters of interest:

- The target colour in the full range of wavelengths in the visible range
- The geometry (size) of the colourfield
- The background the colour is surrounded by (limited to a specific set of colours)

- The ambient light conditions

The group of probands shall comprise of a large pool of individuals representing different ages, genders, social background and cultures. Our experimental setup will help to simplify the measurements of individual tristimulus functions for a more generalized application.

The original SOE has already shown a large variety of individual results, even though the number of probands was very small. Especially for the red primary, the observers have shown large differences in the required colour-mix to get a perceived colour match between the target colour and the mixing colours. With the experimental results we will confirm these differences in the colour matching experiment and move further to quantify the deviation both in wavelength and intensity of the individual tristimulus functions. If the principal shape of the three functions is comparable and the frequency shift is small relative to the full visible range, the experimental setup needed to measure the individual colour-matching functions can be drastically simplified.

Additionally, we pursue the development of a simplified experimental setup that will have a more generalized use. Previous colour-matching experiments using LEDs provide invaluable insight into the technical regarding optics requirements and electronics design (Morvan, Sarkar, Stauder, Blonde, & Kervec, 2011). The setup will consist of a device that can illuminate a test area with a red, blue and green primary of adjustable intensity. With such a mobile colour-matching device, the SOE can be simplified. The simplification of the experiment allows for observers to characterize their individual colour perception in a fast and uncomplicated way. The long-term goal is to develop automated single-observer colour measuring, which can be used to create personalized colour profiles (PERsonalIzed COlour ProfilEs PERiSCOPE), with which we will be able to uniquely calibrate the user's viewing instruments, i.e. screens, printers etc. that are part of a conventional ICC colour management workflow. A simplified but straightforward experiment is the calculation and rendering of an image based on the scaled integral of spectral image data, regarded as spectral reflectance information for each pixel, S(λ, px, py) multiplied by the spectral power distribution of the illuminant I(λ) and e.g. the two extrema of the CIE's color matching functions $x_{min}(\lambda)$, $y_{min}(\lambda)$, $z_{min}(\lambda)$ as well as $x_{max}(\lambda)$, $y_{max}(\lambda)$, $z_{max}(\lambda)$. Such an experimental calculation results in two significantly different images, each representing a rendering based on different experimental data sets of individuals of the SOE. Such different renderings might have a significant effect on the perception of image data and it is a step towards the separation and equalisation of the various effects in the human visual system.

The results and the consequences of the project will be assessed together with experts of art history, media sciences and psychology. We believe that the implications of using personalized color profiles for image renderings will have a strong impact on various fields within the (digital) humanities, which will pave the way for new findings and better understanding. How is e.g. the same rendering of a colour photograph seen by two observers with different physiology? What are the effects of the perception of colour if the colour is adjusted to the physiology and described by of the two observers? How is an observer reacting, if the two observer renderings are shown to the same observer, showing the differences clearly? What effect has such an adjusted colour rendering to the description of eg. colour aesthetics? What is the consequence of seeing an image which is rendered for colour according to the data other person, in other words, if we see an artwork through the eyes of another person, eg. the artist itself? Those questions will be discussed in an interdisciplinary framework with other disciplines, especially art history and media sciences.

In terms of research in cultural heritage and art in humanities universities, museums, and other art institutes, our studies can change the way research is performed and will affect the results of this research, as the tools will become available to introduce the aspect of personal perception. Art is to a great extent a personal experience and institutes have to invent ways to make it objective in order to be able to discuss it in more general terms and draw conclusions about its effect in populations, cultures and times that may be foreign to the researchers today. The PERiSCOPE will adapt an artefact's colour on a digital display according to the viewer's profile. Thus it will allow scientists to truly see the same colour image at the same time and will help reduce the subjectivity of judging an artefact's appearance.

The DHLab also operates DaSCH (The National Data and Service Center for the Humanities), which includes a Virtual Research Environment in the humanities for sustainable collaborative work with digital sources. This web-based infrastructure can be ideally used for the discussion and collaborative evaluation of our colour results. It would make it possible for researchers to get a deeper understanding of each other's comments and critique in terms of colour. It would also enable viewers to see a work of art in the way the artist - in case he or she is still living - perceives it. Finally, if we are able to also categorize colour profiles to fit different population groups, the PERiSCOPE will also enable colour specialists (researchers or even industry stakeholders) to use colour in a way that would make the greatest impact to a specific part of the population.

Our research can also greatly impact research in psychology, in terms of personal perception and emotion, by providing new, more accessible methods for measuring and assessing responses to colour stimuli. Much of the knowledge we have about colour perception today comes from the field of psychology. For every colour-related project, researchers have to recreate some form of the SOE. With the PERiSCOPE mobile setup, we will be able to offer a standardised, easy-to-use system that will provide an efficient, reliable and reproducible methodology for these studies.

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