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CIC21 Technical Papers Program: Schedule and Contents

WEDNESDAY NOVEMBER 6, 2013

Welcome and Keynote

Session Chair: Clément Fredembach, consultant

9:00 – 10:00 AM

Keynote sponsored by Hewlett-Packard Company

9:00 **Illuminant Estimation: Back to the Future,** *Graham D. Finlayson, School of Computing Sciences, The University of East Anglia (UK)* **1**

Image colors are biased by the color of the prevailing illumination. Illuminant estimation algorithms attempt to infer the color of the light incident in a scene and then a color cast removal step discounts the color bias due to illumination. However, despite sustained research beginning over 50 years ago, progress has been modest. The best algorithms—now often built on top of expensive feature extraction and machine learning—are only about twice as good as the simplest approaches.

The simplest approaches—of which 'grey-world' and 'max rgb' are examples—are based on the observation that the statistical moments of the image color distribution are biased by illumination e.g. the mean rgb for a given scene viewed under a bluish light must be bluer than the same scene viewed under a whiter illuminant. Yet, these moments themselves are not direct correlates of the illuminant color. Indeed, illuminant estimation papers often start by presenting the rather poor relative performance of the grey-world algorithm.

Many of the algorithms that provide better estimates than grey-world accept the premise that a statistical moments inform us about illuminant color but that 'better' moments than the mean should be used. Better might be judged in statistical terms alone or by adopting a physical constraint (e.g. the addition of the constraint that the color of the light is physically plausible). Unfortunately, calculating more perspicacious statistics and implementing the recommended physical constraints is often quite complex (orders of magnitude more complex than calculating the mean color) and the performance increment—if there is one—is small.

As well as reviewing the development of the field – from inception to the current leading algorithms—and explaining why the performance increment is modest, we also present a new promising approach. Remarkably, we will show that simple statistical moments (e.g. the mean edge color) with the addition of a correction step provides the best illuminant estimation procedure evaluated on current datasets. The simple grey-world type algorithm—proposed 50 years ago—with a twist works very well indeed.

Inside the Rainbow

Session Chair: Geoff Woolfe,
Canon Information Systems Research Australia Pty. Ltd.

10:00 – 10:50 AM

10:00 **Spatially Resolved Joint Spectral Gamut Mapping and Separation (Focal),** *Sepideh Samadzadegan and Philipp Urban, Technische Universität Darmstadt (Germany)* **2**

The paramer mismatch-based spectral gamut mapping framework is an approach which optimizes the spectral reproduction colorimetrically for multiple viewing conditions. Unfortunately, due to the pixelwise nature of this method, almost similar neighboring pixels might be mapped to completely different colorants which yield disturbing banding artifacts. The previous proposed solution for this problem adds some noise to the a^* and b^* channels of the input images prior to calculating the separation image. Even though this procedure solves the problem of banding artifacts, it adversely affects the graininess of the final print. In this paper, we propose an approach based on both colorimetric and spatial criteria to reduce banding artifacts of the final print. To our knowledge, the proposed method is the first attempt of joint spatio-spectral gamut mapping and separation. It leads to smoother spectral separations by preserving image edges but is still not completely free of artifacts.

10:30 **Multispectral Imaging Using LED Illumination and an RGB Camera,** *Raju Shrestha and Jon Yngve Hardeberg, Gjøvik University College (Norway)* **8**

LED illumination based multispectral imaging is getting much attention in recent years due to its fast computer controlled switching ability, availability of many different LEDs, robustness, and cost effectiveness. In this paper, we propose a system which uses an RGB camera along with two or three combinations of three different types of LEDs in order to acquire multispectral images of six or nine channels. Optimal LED combinations are selected so as to produce accurate estimate of spectral reflectance and/or color. The system is rather simple to realize. Moreover, it is faster as it requires only two or three shots, unlike state of the art multiplexed LED illumination based systems which require as many shots as the number of channels that a system can acquire. The proposed system can be useful in general multispectral imaging applications. The system has been evaluated with both the natural images and paintings. The results from the simulation experiments were promising, indicating the possibility of the proposed system as a practical and feasible method of multispectral imaging.

10:50 – 11:30 AM Coffee Break

Beyond the Rainbow

Session Chair: Po-Chieh Hung, Konica Minolta Laboratory USA, Inc.
11:30 AM – 12:30 PM

11:30 **An Eleven-Band Stereoscopic Camera System for Accurate Color and Spectral Reproduction,** *M. Tsuchida, K. Kashino, and J. Yamato, NTT Corporation (Japan)* **14**

For accurate color and spectral reflectance reproduction, we propose a novel eleven-band acquisition system using a nine-view stereo camera. The proposed system consists of eight monochrome cameras with eight different narrow band-pass filters and an RGB camera. To generate an eleven-band image, the shapes of the nine captured stereo images are transformed to correct registration displacement caused by stereo parallax. In the process of correspondence search between stereo images, the phase-only correlation method (POC) is used. The most significant point of our method is that the captured RGB image is converted into narrow-band images for accurate correspondence search. The detected corresponding points are used for estimating parameters of image transformation and an eleven-band image is generated. By comparing with conventional method, experimental results show that the accuracy of correspondence detection and spectral reflection estimation is improved

11:50 **Spectra from Correlation,** *Peter Morovic, Ján Morovic, and Juan Manuel García–Reyero, Hewlett Packard Company (Spain)* . . **20**

Spectral reflectance is a key material property and contributor to object appearance. While it has long been known that reflectance in a given wavelength interval correlates strongly with reflectances in neighboring ones, this correlative property has only been exploited implicitly before. The present paper therefore presents a new approach to spectral analysis and synthesis that consists of first deriving a spectral correlation profile and then using it for a direct and full sampling of the spectral and color gamuts corresponding to it. The resulting technique can be used to generate natural-like spectra (or spectra following other, specific correlation properties) and it can also be incorporated into Bayesian models of spectral estimation.

12:10 **Spatio-Spectral Image Restoration,** *Christoph Godau and Philipp Urban, Technische Universität Darmstadt (Germany)* . . .**27**

The recovery of spectral reflectances from camera responses is usually composed of several distinct operations. We propose a new approach that connects edge-preserving denoising, deblurring and spectral reconstruction. Each of the steps is based on actual physical properties of the camera system that can be obtained using established methods, and the filter eliminates the need for manual sharpening of the images. Results on both real images and synthetic data show significant improvements over previous methods for spectral reconstruction.

12:30 – 2:00 PM Lunch Break

Bright Ideas

Session Chair: M. Ronnier Luo, University of Leeds
2:00 – 3:20 PM

2:00 **Extreme Spectral Power Distribution of Light Source and its Impact to Vision and Cameras Sensitivity,** *Po-Chieh Hung, Konica Minolta Laboratory U.S.A., Inc. (USA)* **33**

Thanks to the advancement of technologies, we may be having more flexibility to determine the spectral power distribution (SPD) of light sources. Suppose any SPD is possible, we derive "extreme SPD of light source" aiming at a specific purpose such as the lowest energy, the largest color gamut, the lowest impact to fine arts, etc. We found that these SPDs always consist of multiple spikes when very high CRI is not required while the SPD of the black body radiation is continuous in wavelength. In order to investigate the effect of such light sources to human visual system and camera system, we employ two types of such light sources, namely Maximum White Luminous Efficacy of Radiation (MWLER), which gives the best energy efficiency, and Maximum Gamut Area (MGA), which gives the largest color gamut size. Both MWLER and MGA are composed of multiple spikes in wavelength. We generate such SPDs with respect to 6 types of existing light sources with same CCT and CRI (if applicable), and evaluate how sensitive these are with 10 sets of color matching functions (CMFs) given by Stiles and Burch as human visual system and 4 sets of digital camera sensitivities by computer simulation. We presume a color matrix of color conversion for CMFs and camera is adjusted minimizing errors with a Macbeth Color Checker under black body radiation with the white point constraint. With this assumption, we evaluate colorimetric error under the two extreme SPDs in addition to black body radiation and existing light sources. We find that cameras give large error (more than 20 in ΔE^*_{ab}) for these spiky light sources which may not be accepted by users even when they are in a tolerable error range for the human visual system. It is concluded that such spiky light source could be used without problem for a variation of CMFs, but it would be problematic for color reproduction of cameras.

2:20 **Monitor Brightness Perception Changes under Various Surround Condition,** *Ye Seul Baek and Youngshin Kwak, Ulsan National Institute of Science and Technology, and Seung-ok Park and Hong-suk Kim, Daejin University (South Korea)* **39**

The monitor brightness is affected by surround condition. Six natural test stimuli were estimated in terms of perceived brightness to investigate the surround luminance effect. Each of the test stimuli was displayed on a LCD. The nine surround conditions were controlled by illuminator which was placed behind the monitor. The magnitude estimation method was used to find out the effect of surround for perceived brightness. It was found that surround luminance influence the perceived brightness only under S_R>1.

CIECAM02 brightness (Q) was tested. The brightness was poorly predicted and there was not correlated to observer's visual data well. For this reason, the Q was modified. First, surround parameter c was optimized using the linear interpolation based onSR (surround ratio). It showed the better performance than those of original CIECAM02, under SR>1. Second, the ratio of visual brightness and Q using the optimized c' was fitted against the SR to compensate the surround luminance. As a result there was an improvement of the performance.

2:40 **Perceiving Gloss in Surfaces and Images,** *Adria Fores and James Ferwerda, Rochester Institute of Technology, and Ingeborg Tastl and John Recker, Hewlett-Packard Laboratories (USA)* **44**

Color Appearance Models are successfully used to model the color perception differences seen when the same stimuli are presented on different media, e.g. hard copy or a self-luminous display. It is currently unknown if the similar effects are present in gloss perception and if there is need for Gloss Appearance Models.

Gloss communication, and the higher level material appearance communication is becoming more important everyday with the increase in customized manufacturing and the need for the costumer to preview a final product while short-runs, time and cost constraints prohibit the use of hard-copy proofs.

Three experiments are proposed in order to analyze this phenomenon. The Gloss matching performance of observers on real objects is first going to be studied. Then, the same experiment will be repeated with synthetic images. Finally, a cross-media matching experiment will be performed, where the observers will have to match a real material with synthetic representations.

The same trend was observed in the experiment using only real objects and in the cross-media situation, where a high matching accuracy was obtained for low gloss samples, and the gloss of mid and high gloss samples was underestimated. The same accuracy for low gloss samples was obtained for the experiment with only synthetic images, but mid and high gloss samples were overestimated. The sensitivity of the observers was higher when only real samples were used, it decreased when the display was used due the lack of visual disparity and multiple viewing conditions, and it was lowest on the last experiment, influenced by the multiple media and the above limitations.

3:00 **Chromaticity Limits in Color Constancy Calculations,** *John McCann, McCann Imaging (USA); Vassilios Vonikakis, Advanced Digital Sciences Center (Singapore); and Cristian Bonanomi and Alessandro Rizzi, University of Milan (Italy)* **52**

There are two very different kinds of color constancy. One kind studies the ability of humans to be insensitive to the spectral composition of scene illumination. The second studies computer vision techniques for calculating the surface reflectances of objects in variable illumination. Camera-measured chromaticity has been used as a tool in computer vision scene analysis. This paper measures the ColorChecker test target in uniform illumination to verify the accuracy of scene capture. We identify the limitations of sRGB camera standards, the dynamic range limits of RAW scene captures, and the presence of camera veiling glare in areas darker than middle gray. Measurements of scene radiances and chromaticities with spot meters are much more accurate than camera capture due to scene-dependent veiling glare. Camera capture data must be verified by calibration.

3:20 – 4:00 PM Coffee Break

Heavy Metal

Session Chair: John McCann, McCann Imaging

4:00 – 4:20 PM

4:00 **Specular Color Imaging on a Metallic Substrate,** *Petar Pjanic and Roger D. Hersch, École Polytechnique Fédérale de Lausanne (EPFL) (Switzerland)* **61**

We propose a full reproduction workflow for printing color images on metallic substrates. It relies on an ink spreading enhanced cellular Yule-Nielsen modified spectral Neugebauer model, calibrated with 35 color samples printed on the metal film and measured under specular reflection. The calibration accounts for the different phenomena contributing to the reflectance of halftone prints on metal: specular reflection by the metal film substrate of light traveling across the inks, illumination and viewing geometry, shadowing effect induced by the ink and difference in surface structure between the inked and non-inked metal halftone elements. The model enables predicting printable colors with an average CIELAB ΔE_{94} error of 1.7. Thanks to the model, the metal print gamut is established and a 3D table provides the correspondence between printable metallic colors viewed under specular reflection and the corresponding ink surface coverages. The input sRGB gamut is mapped into the print gamut. At halftone image generation time, surface coverages of the inks yielding the desired gamut mapped input colors are obtained from the 3D table. These ink surface coverages yield the ink separations that are halftoned and printed. The resulting color images printed on a silver substrate viewed under specular reflection reproduce the hues at a high degree of fidelity. The luminance of metallic prints under specular observation is generally higher than the luminance of paper under the same illuminating conditions. Therefore, the printed metallic colors appear more colorful. Such metal prints are attractive for design, art and publicity. Their high brightness immediately strikes the observer and transmits the message incorporated into the reproduced picture or artwork.

Heavy Metal Panel

4:20 – 5:30 PM

Moderator: Danny Rich, SunChemical
Panelists:
Mike Nofi, Flex Products / JDS Uniphase Custom Color Solutions
Greg Shrider – Byk-Gardner,USA
Rich Knapp, X-Rite, Inc
TBA, Qualcomm

Evening Talk

Session Chair: Jennifer Gille, Qualcomm QTI

8:00 – 9:00 PM

8:00 **Sticks, Flowers, Fibers: In the Footsteps of New Mexico's Prehistoric and Colonial Color Engineers,** *Glenna Dean, Abiquiu Dye Studio (USA)*

THURSDAY NOVEMBER 7, 2013

Award Presentations and Keynote

Session Chair: Alex Forsythe,
Academy of Motion Picture Arts and Sciences

9:00 – 10:00 AM

Keynote sponsored by Canon USA

Canon

9:00 **The Art and Science of Film Restoration,** *Schawn Belston, 20th Century Fox (USA)**

Colorful Language

Session Chair: Stephen Westland, University of Leeds

10:00 – 10:50 AM

10:00 **Automatic Color Palette Creation from Words (Focal),** *Albrecht Lindner and Sabine Süsstrunk, École Polytechnique Fédérale de Lausanne (EPFL), Switzerland* **69**

We present an automatic framework to extract color palettes from words. This is a novel approach in comparison to existing solutions, *e.g.* manual creation or extraction from images. The associations between words and colors are deduced from a large database of 6 million tagged images using a scalable data-mining technique. The palette creation can be constrained by the user to achieve a desired hue template. We first focus on single words and then extend to entire texts. We compare our results against Adobe Kuler, a widely used online platform of manually created color palettes. We show that our approach performs slightly better than its non-automatic counterpart in terms of user's preference rankings. This is a good result because our method is fully automatic whereas Kuler relies on users' palettes that are manually created and annotated.

10:30 **A Robust Hue Descriptor,** *Hamidreza Mirzaei and Brian Funt, Simon Fraser University (Canada)* **75**

A hue descriptor based on Logvinenko's illuminant-invariant object colour atlas is tested in terms of how well it maps hues to the hue names found in Moroney's Colour Thesaurus and how well it maps hues of Munsell papers to their corresponding Munsell hue designator. Called the KSM hue descriptor, it correlates hue with the central wavelength of a Gaussian-shaped reflectance function. An important feature of this representation is that the set of hue descriptors inherits the illuminate invariant property of Logvinenko's object colour atlas. Despite the illuminant invariance of the atlas and the hue descriptors, metamer mismatching means that colour stimulus shift can occur, which will inevitably lead to some hue shifts. However, tests show that KSM hue is robust in the sense that it is much more stable under a change of illuminant than CIELAB hue.

10:50 – 11:30 AM Coffee Break

*no abstract available

Picture Perfect

Session Chair: Johji Tajima, Nagoya City University
11:30 AM – 12:30 PM

This paper proposes a method to extract artists' color features of art paintings, and correct the color-mismatch images of paintings based on artists' color features. First, we describe a standard image database consisting of famous oil paintings we captured directly, and an algorithm for extracting artists' color features based on the color distribution of the standard image data for each artist. The color distribution is analyzed by PCA and described with an ellipsoid to represent the standard color features for the artist. It is suggested that the color features for the respective artists are similar to the human visual assessment of their paintings. Next, the color correction is based on the coordinate transformation of pixel values in a color-mismatch image so that the color features of the mismatched image are fitted to the artist's color features in the standard image database. We present a correction algorithm using sRGB and CIELAB color spaces. Experiments are performed using samples of color-mismatch images of the famous oil paintings.

The advance in camera and imaging technologies has made digital archiving and conservation of artworks possible in museums. Visual editing and retouching are usually made by experts in museums to match the reproduction with the original more closely. While effective, visual editing and retouching is time-consuming and labor-intensive. We addressed this problem by learing from the adjustments made by observers, and automatically making visual editing and retouching on incoming paintings. The evaluation results suggest that the image adjusted by our model is significantly better than the average of the images adjusted by observers.

A new colour difference dataset has been developed to address the specific needs of the graphic arts industry. An experiment has been designed with 1288 colour pairs. Concretely 46 colour centres of the Fogra media wedge and 28 randomly intra- and supra threshold test colours around each of them have been observed by 32 observers. The pair comparison constant stimuli method has been used by means of three grey reference pairs comprising colour differences of ΔL=1, 3 and 5. The performance of established and modern colour difference formulae has been evaluated with the new dataset. DIN99o and CIEDE2000 outperformed the other tested metrics.

Interactive Previews

Session Chairs: Marius Pedersen, Gjøvik University College, and Norimichi Tsumura, Chiba University
12:30 – 1:00 PM

A high spatial resolution imaging colorimeter and gloss-meter is presented. The combination of a high quality imaging colorimeter with an off axis imaging optics and a highly stabilized RGB LED source allows color and gloss measurements of small parts with high accuracy. The characteristics of the system with some experimental results on black coated and printed papers are presented.

We investigate the influence of scene illuminant on perceived image quality. Given two multispectral images, an original and a reproduction (e.g. compressed, gamut mapped,..), we seek redundancies of perceived difference through changes of illuminant, and with regard to 5 so-called image difference features (IDF). In order to do this, we employ an information-theoretic perspective to measure variations of entropies in each IDF, w.r.t. various scene illuminants, and in the case of two particular kinds of distortions: spectral gamut mapping and a spectral reconstruction from a six-channel camera model. Our results indicate that changing the scene illuminant has a lesser influence on achromatic image difference features.

The RGBZ sensor is a novel imaging sensor that captures both color and depth images simultaneously in a single chip, with a specially designed color-filter-array (CFA), in which some of the RGB color pixels are replaced by "Z" pixels that capture depth information but no color information. As a result, RGB color images produced by this pixel array appear degraded, with missing RGB values or "holes" at locations occupied by the Z pixels. To fill in these "holes", and thus restore resolution and appearance of color images, we propose a Patch-Clone method that exploits redundant texture information in the scene. Derived from the non-local approaches, our method consists of two steps: 1) a matching step to identify the candidate patch that contains the most useful information to reconstruct the color pixels missing at a particular hole; 2) a cloning step to copy the content from the candidate to fill in the hole. When higher order pixel content is copied, pixel continuity between the restored and original pixels can be enforced. The result of the proposed method is full resolution Bayer images, to which existing common demosaic algorithms can be applied. Tests show that the proposed method provides better reconstruction result in term of distortion error as well as visual appearance.

Characterization data from 9 displays are used to demonstrate the capability of the primary stability-based metrics.

Principal Component Analysis for Pigmentation Distribution in Whole Facial Image and Prediction of the Facial Image in Various Ages, *Saori Toyota,[1] Izumi Fujiwara,[1] Misa Hirose,[1] Nobutoshi Ojima,[2] Keiko Ogawa-Ochiai,[3] and Norimichi Tsumura[1]; [1] Chiba University, [2]Kao Corporation, and [3]Kanazawa University Hospital (Japan)* **148**

In this paper, we apply principal component analysis to pigmentation distribution in whole face and obtain feature values. Furthermore, we estimate the relationship between the obtained vectors and the ages and simulate the changes of women facial image from in her 20s to in her any age by multiple regression analysis. Human faces is the well-known part which receive a lot of attention in the body. Changing the small quantity of the features in faces make large differences in their appearance. The features which we can receive divide broadly into two categories. One is the physical feature such as skin condition and its shape, and another one is the psychological features such as the ages and the health. In the beauty industry it is required to synthesize the skin texture based on the two kinds of the feature values. Previous works remain in the analysis of the skin texture using small area. By morphing shape of facial images to that of average face and extending the analyzed area to whole face, our method can analyze pigmentation distribution in whole face and simulate appearance of face by changing the age.

Maximum Entropy Spectral Modeling Approach to Mesopic Tone Mapping, *Mehdi Rezagholizadeh and James J. Clark, McGill University (Canada)* **154**

Tone mapping algorithms should be informed by accurate color appearance models (CAM) in order that the perceptual fidelity of the rendering is maintained by the tone mapping transformations. Current tone mapping techniques, however, suffer from a lack of good color appearance models for mesopic conditions. There are only a few currently available appearance models suited to the mesopic range, none of which perform very well. In this paper, we evaluate some of the most prominent models available for mesopic and scotopic vision and, in particular, we focus on the iCAM06 model as one of the best-known tone reproduction techniques. We introduce a spectral-based color appearance model for mesopic conditions which can be incorporated in tone reproduction methods. Based on the maximum entropy spectral modeling approach of Clark and Skaff, this is a powerful color appearance model which can predict the color appearance under mesopic conditions as well as under photopic conditions. Our model incorporates the CIE system for mesopic photometry, leading to increased accuracy of color appearance model. At low (mesopic) light levels two factors come into play as compared with high light level (photopic) spectral modeling. The first is that image noise becomes significant. The Clark and Skaff model treats the noise as an inherent part of the modeling process, and an estimate of the noise level sets the tradeoff between the consistency of the solution with the measurements and the spectral smoothing imposed by the maximum entropy constraint. The second factor in mesopic vision is that both the rod and the cone systems are active, requiring a modification to the sensor model. The relative contribution of the rod and cone systems is dependent on the overall light level in this regime, and our approach is adaptive in this sense. We present several experiments comparing the performance of our tone mapping approach with that of the existing methods, showing that the proposed method works very well in this regard, and also demonstrates the potential of our model to become a part of wide-range tone mapping systems.

Colorimetric Characterization of a 3D Printer with a Spectral Model, *Brittany D. Hensley and James A. Ferwerda, Rochester Institute of Technology (USA)* **160**

As 3D printing becomes an increasingly popular technology, knowledge of the processes employed by a printer becomes more important. In this paper, one particular printer, the Zcorp Spectrum Z510, is studied in terms of its color production. Two approaches to a spectral model are evaluated in terms of their ability to predict output colors of the printer based on input RGB values. The models and their performance are presented below.

Display Characterization for Moving Images, *Marjan Vazirian, Vien Cheung, and Stephen Westland, University of Leeds (UK)* **167**

Color characterization of a display device commonly requires the measurement of CIE XYZ values of known samples displayed as patches on the device so that the relationship between the device space (usually RGB) and the device-independent space (XYZ) can be determined. However, it is known that the color measurements of the patches may vary with the color and luminance of the background against which they are displayed. Lack of spatial independence is one of the factors that can cause this phenomenon. This raises the question of what the nature of the background should be for an optimal characterization of a display system. It is likely that what is optimal will depend upon the intended application of the characterized display (for example, is it being used to display simple images in a psychophysical experiment or more complex images in some other setting). This research considers characterization with two background conditions (Mondrian-like colored background and Mondrian-like colored background with motion) and explores the effect of these background effects on the characterization model's parameters and on the usefulness of the characterization in various practical scenarios.

1:00 – 2:30 PM Lunch Break

Do You See What I See?

Session Chair: Caterina Ripamonti, UCL Institute of Ophthalmology
2:30 – 3:30 PM

2:30 **Observer Variability Experiment Using a Four-Primary Display and its Relationship with Physiological Factors,** *Yuta Asano and Mark D. Fairchild, Rochester Institute of Technology (USA) and Laurent Blondé, Technicolor (France)* **171**

There exist individual differences in color matching functions and the use of a single standard observer as a representative of a whole population often limits the accuracy of color reproduction, especially for narrowband stimuli. We conducted a paired comparison experiment for 58 color-normal people involving color difference judgments using four nearly metameric spectra pairs. The performance of observer functions: CIEPO06, Sarkar's observers, and the extended CIEPO06 incorporating peak-shift in L and M cones were investigated. Large observer variability was found in the obtained results, which ismuch larger than what CIEPO06 predicts. At least two different groups were found in the experimental results, which could be

explained by eye-lens and macular pigment optical density variations. We estimated the individual cone fundamentals from another experiment where observers performed five color matching, and used them to predict the paired comparison results. They gave better, or at least comparable prediction to those of CIE 1964 observer and CIEPO06.

2:50 **The NCS-Like Colour Scales Based on CIECAM02,** *M. Ronnier Luo,[1,2] Guihua Cui,[3] and Yoon Ji Cho[2]; [1]Zhejiang University (China), [2]Leeds University (UK), and [3]Wenzhou University (China)* **177**

The NCS scales of whiteness, blackness and chromaticness were developed based on CIECAM02 and CAM02-UCS. They gave satisfactory prediction to the NCS data.

3:10 **Experiment on the Relation between Color Discriminability and Genetic Polymorphism in the L Cone Using Four Color Primary Display Device,** *Johji Tajima, Go Tanaka, Mieko Suzuki, and Akihiro Moriyama, Nagoya City University, and Yasuhiro Yoshida, Sharp Corporation (Japan)* **180**

In this study, the correlation between the color discrimination ability and the genetic polymorphism is investigated. It is known that the variation in spectral sensitivity of the L cone is common among normal color vision subjects. It is due to the genetic polymorphism in cone pigments (opsins). The 180th amino acid residue of the L cone opsin is frequently replaced from serine to alanine. It is also known that due to the replacement the wavelength of the L cone peak sensitivity shifts about 6nm to the short wavelength direction. Assuming that the neural processing in the neurons and the brain is the same for both the standard observer and the observer whose spectral sensitivity of the L cone opsin shifts by 6nm (shift observer), we designed color pairs so that the color difference between the pairs looks larger to the standard observer than to the shift observer. To extend the color difference only for one of the two observers, the four primary color display 'Quattron' developed by SHARP Corporation was used. The experimental results, surprisingly, showed that the subjects whose 180th amino acid residue of the L opsin is alanine could better discriminate the pairs of colors that were designed to be discriminated by the standard observer. This result may mean that the neural processing is dependent on the polymorphism, and the human color discriminability variation cannot be explained simply by the cone spectral sensitivity shift.

Playing with Color

Session Chair: Peter Morovic, Hewlett-Packard Company

3:30 – 4:10 PM

3:30 **Metameric Observers: A Monte Carlo Approach,** *Mark D. Fairchild and Rodney L. Heckaman, Rochester Institute of Technology (USA)* **185**

No two observers perceive color the same. To one observer, the colors of two objects might match perfectly; yet to another, those same two objects might not match depending on the spectral characteristics of the colors of the two objects, their illuminant, and each of the observer's spectral eye response. Here we create a large, representative group of such observers—said to be metameric—from data that characterizes the variability in these characteristics over the human population. Further, we show that the degree of mis-match between any metameric pair of objects might be large enough that the color naming of each object can be different for certain observers.

3:50 **Improved Simulation of Image Detail Visibility Using the Non-Subsampled Contourlet Transform,** *Marius Pedersen, Xinwei Liu, and Ivar Farup, Gjøvik University College (Norway).* **191**

A previous study proposed a method for simulation of detail visibility of natural images (from different observation distances) by using contrast sensitivity functions and wavelets (Pedersen and Farup, Color and Imaging Conference 2012). In this paper we propose an improved method using the non-subsampled contourlet transform, which accounts for important aspects of the human visual system such as orientation sensitivity. In addition we account for the effect of surround illumination. Objective and subjective evaluations show that the proposed methodology is promising, and that it introduces fewer artifacts than the previous method.

4:10 – 6:00 PM Interactive Paper Session

7:30 – 9:30 PM Conference Reception

FRIDAY NOVEMBER 8, 2013

Friday Keynote

Session Chair: Sabine Süsstrunk, École Polytechnique Fédérale de Lausanne

9:00 – 10:00 AM

9:00 **Color Reproduction and Beyond,** *Roger D. Hersch, École Polytechnique Fédérale de Lausanne (EPFL) (Switzerland)* **197**

"Is research in color reproduction not completely outdated? Since anyone can print perfectly looking color pictures, hasn't everything been solved ?" In reply to these questions, let us give an overview about the current state of the art in classical color reproduction and outline both solved and unsolved problems. We then describe actual and future challenges.

The Skinny on Color

Session Chair: Xuemei Zhang, Apple Inc.

10:00 – 10:50 AM

10:00 **A Colour Palette for Automatic Detection of Blue-White Veil (Focal),** *Ali Madooei amd Mark S. Drew, Simon Fraser University (Canada)* . .**200**

Colour assessment of pigmented skin lesions are essential for the diagnosis of malignant melanoma. However, visual interpretation of colour is subjective and prone to error. Computer programs can provide support to clinicians to overcome this subjectivity. So far, methods for colour analysis of this nature have utilised statistical classification models. This paper puts forward an al-ternative framework: an effort to reproduce the experience of hu-man observer. The proposed method introduces a perceptually intuitive and semantically meaningful approach for colour and colour-related feature detection. As a case study, the task of au-tomatic detection and segmentation of blue-white veil feature in dermoscopy

images is examined. Our proposed method, as shown in our experiments, outperforms the prior art for this task, while it attempts to mimic the human perception of skin lesion colours.

10:30 **Developing a 3D Colour Reproduction System for Additive Manufacturing of Facial Prostheses,** *Kaida Xiao,[1,2] Faraedon Zardaw,[1] Richard van Noort,[1] Sophie Wuerger,[2] and Julian M. Yates;[3] [1]the University of Sheffield, [2]University of Liverpool, and [3]University of Manchester (UK)* **206**

A new 3D colour image reproduction system is proposed for automatic and accurate additive manufacturing of facial prostheses. The general framework of colour image reproduction was defined and a protocol for each sub-process was developed for this specific application. Prototypes of both nose and ear prostheses were produced using the proposed system. The produced facial prostheses are capable of providing accurate shape, fine texture and improved colour reproduction, with significant savings in both time and cost.

10:50 – 11:40 AM Demo Discussion and Coffee Break

Putting Color to Work

Session Chair: Youngshin Kwak,
Ulsan National Institute of Science and Technology
11:40 AM – 12:40 PM

11:40 **8 Vvertex HANS: An Ultra-Simple Printer Color Architecture,** *Ján Morovic, Peter Morovic, Martí Rius and Juan Manuel García–Reyero, Hewlett Packard Company (Spain)* **210**

The underlying non-linearity of how print colorants combine makes color control in printing significantly more complex than for other color imaging devices. While in additive systems a measurement of their few primaries and per-channel non-linearities versus luminance is a sufficient basis for predicting color output, printing typically requires the measurement of a large number of colorant combinations. This requirement for many measurements makes accurate color output more challenging and means that setting up a printing system's color control can be time consuming and costly. The solution presented in this paper involves a new use of the HANS approach, which instead of print optimization looks for simplifying print color formation and therefore also control. In a nutshell this can be achieved by only ever combining eight basic colorant patterns, which results in a display-like color gamut and allows for color control on the basis of their eight measurements and those of the printing system's optical dot gain.

12:00 **Color Correction for Tone Reproduction,** *Tania Pouli,[1,5] Alessandro Artusi,[2] Francesco Banterle,[3] Ahmet Oguz Akyüz,[4] Hans-Peter Seidel,[5] and Erik Reinhard;[1,5] [1]Technicolor Research & Innovation (France), [2]University of Girona (Spain), [3]Visual Computing Lab ISTI-CNR (Italy), [4]Middle East Technical University (Turkey), and [5]Max-Plack-Insitut für Informatik (Germany)* **215**

High dynamic range images require tone reproduction to match the range of values to the capabilities of the display. For computational reasons as well as absence of fully calibrated imagery, rudimentary color reproduction is often added as a post-processing step rather than integrated into the tone reproduction algorithm. However, in the general case this currently requires manual parameter tuning, although for some global tone reproduction operators, parameter settings can be inferred from the tone curve. We present a novel and fully automatic saturation correction technique, suitable for any tone reproduction operator, which exhibits better color reproduction than the state-of-the-art and we validate its comparative effectiveness through psychophysical experimentation.

12:20 **Integrated Color Matching Using 3D-Distance for Local Region Similarity,** *Ran Shu, Ho-Gun Ha, Dae-Chul Kim, and Yeong-Ho Ha, Kyungpook National University (South Korea)* **221**

Color consistency in stereoscopic content is important for 3D display systems. Even with stereo cameras of the same model and with the same hardware settings, complex color discrepancies occur when acquiring high quality stereo images. Global matching can reduce global color discrepancies, but it is not sufficient with local color discrepancies due to different objects having different reflections and imaging models where a more exhaustive and precise process is needed. Therefore, the local matching method is added for reducing local color discrepancies. In this paper, we propose an integrated color matching method that uses an estimated 3D-distance for the stage of local matching. The distance between the current pixel and the target local region is computed using depth information and the spatial distance in the 2D image plane. The 3D-distance is then used to determine the similarity between the current pixel and the target local region. The overall algorithm is as follows. First, the cumulative histogram matching is introduced for reducing global color discrepancies. Then, the proposed local color matching is established for reducing local discrepancies. Finally, a weight-based combination of global and local matching is computed. Experimental results show the proposed algorithm has improved global and local error correction performance for stereoscopic contents with respect to other approaches.

12:40 – 2:00 PM Lunch Break

Hard-core Color Theory

Session Chair: Jennifer Gille, Qualcomm QTI
2:00 – 3:20 PM

2:00 **Spectrum-Locus Convexity: A Metric for Cameras?,** *Michael H. Brill, Datacolor (USA)* **227**

Spectrum-locus convexity confers to human vision the property that optimal colors are 1-0 with at most two transition wavelengths. It also confers illuminant-invariance of the CW/CCW chromaticity ordering of certain reflectance triads. The same holds for cameras, and provides a less stringent criterion for camera quality than that of Maxwell and Ives. Unlike in applications that design reflectance spectra, the camera convexity criterion has the goal of ensuring that cameras and humans share the same non-reversing reflectance triads, not of ensuring illuminant-invariance of the triads themselves. Convexity may be a useful metric, but is undefined when the sensors are non-overlapping. This paper will qualitatively explore these issues.

2:20 **Hard-core Panel: Non-Convexity of the Spectrum Locus: A Crime Against Color Rrder? How Guilty is Human Vision?**
Moderator: Michael Brill, Datacolor
Panelists: Pouya Bastani, Simon-Fraser University
Mark Fairchild, RIT
Brian Funt, Simon-Fraser University
Po-Chieh Hung, Konica-Minolta
Ján Morovic, Hewlett Packard Company
Eric Walowit, consultant

3:20 – 3:40 PM Coffee Break

Late Breaking News

Session Chair: Jennifer Gille, Qualcomm QTI
3:40 – 4:10 PM

****High Dynamic Range Imaging: Is the Game Worth the Candle? (Interactive),** *Klaus Simon, Iris Sprow, Sofia Baranczuk, Ursina Caluori, Dennis Kuepper, Matthias Scheller Lichtenauer, and Peter Zolliker, Empa (Switzerland)* **231**

High dynamic range imaging (HDRi) is a technology concerned with representing a range of luminances larger than state of the art displays and closer to luminance ranges occuring in natural scenes. We investigate whether the approach of evaluat-ing a dynamic range by the number of just noticeable differences contained within does make sense in a HDRi workflow. We found that disturbing effects of neighboring luminances were hardly perceivable on a standard dynamic range display if the background luminance exceeds 5 cd=m^2.

****On the Information Content along Edges in Trichromatic Images (Interactive),** *Shahram Peyvandi,[1] Juan L Nieves,[2] and Alan Gilchrist[1]; [1]Rutgers, The State University of New Jersey (USA) and [2] Universidad de Granada (Spain)* **236**

We introduce a theoretical framework for measuring the information content in the edges extracted from a color image. The main difficulty in estimating the amount of information (differential entropy) in an image signal is to fit an appropriate probability mass function to the trichromatic image data. To estimate the amount of information in the edges extracted from a color image, we first convolve the image with a derivative filter. By fitting a Kotz-Type probability distribution to the convolved image, we then estimate the differential entropy of the edge coefficients as a measure of the uncertainty involved in the edge content of a postreceptoral chromatic image. The proposed estimation of differential entropy provides an efficient means of processing the edge content information under a variety of natural illuminations, which might be further used as a quantitative measure for evaluating color constant image retrieval.

3:40 **Real-Time Spectral Rendering,** *C. Allen Waddle, University of Victoria (Canada)* **240**

The common practice in computer graphics of multiplying RGB triplets to model the perception of reflected light is simple and efficient, but it does not predict color reliably, nor can it model metamerism or optical phenomena that are spectral in nature, such as iridescence. Spectral rendering meets these goals, but the O(n) cost incurred in multiplication of n-dimensional spectra can be prohibitively expensive. Although spectra can be well approximated by linear combinations of m<<n basis vectors, standard linear models lead to matrix-vector multiplication with complexity O(m^2) when performing lighting calculations in the lower-dimensional space. A method by Drew and Finlayson reduces this cost to O(m) with a "sharp" basis that has been transformed by an m × m matrix **T**, each column of which is the solution to an optimization problem requiring specification of an interval of wavelengths. Choosing good intervals, however, is itself an optimization problem, which the authors neither pose nor solve. Instead, we construct **T** by optimizing the sharpness of a basis and the minimum angle between its vectors, but obtain better results by minimizing the residual error explicitly. Alternatively, by minimizing a weighted subspace projection we can solve a simpler problem that converges to the same minimum-residual solutions.Testing these methods with a variety of spectra, we obtain good accuracy with as few as four dimensions, permitting real-time rendering at arbitrarily high spectral resolutions for a cost that is only a fraction above that of RGB rendering.

3:55 **A Simplified Overprint Model and Why the Masking Equations "Sort Of" Work for Color Halftone Hardcopy,** *J.A. Stephen Viggiano; Acolyte Color Research (USA)* **247**

The linear masking equations, inspired by continuous tone photographic color, were applied by Murray, et al., to halftone printing. This model is considerably simpler than models customarily used for halftone color hardcopy, such as those based on Neugebauer. Despite unrealistic assumptions regarding the image microstructure, the masking equations often perform reasonably well.

In this paper, the differences between the linear masking model and the model of Yule and Colt (Neugebauer with wide-band Yule-Nielsen correction applied) are parsed. It is shown that, under conditions for which the Yule-Nielsen parameter n grows without bound (or its reciprocal, u, approaches zero), the differences can be attributed to sub-additivity of densities. An approximation is offered to model the sub-additivities.

The largest difference between the two models can be expected to occur under normal circumstances when all colorants are printed solid.

Closing Keynote and Best Paper Awards Presentations

Session Chair: Vien Cheung, University of Leeds
4:10 – 5:15 PM

4:10 **Controversial Color,** *Sabine Süsstrunk, École Polytechnique Fédérale de Lausanne (Switzerland)**

Best Student Paper Award sponsored by MERL

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**These papers will be previewd during the Interactive Preview Session on Thursday from 12:30-1:00 pm and presented that afternoon from 4:20 – 6:00 pm during the Interactive Paper Session.

*no abstract available