Assessing Color Reproducibility of Whole-Slide Imaging Scanners

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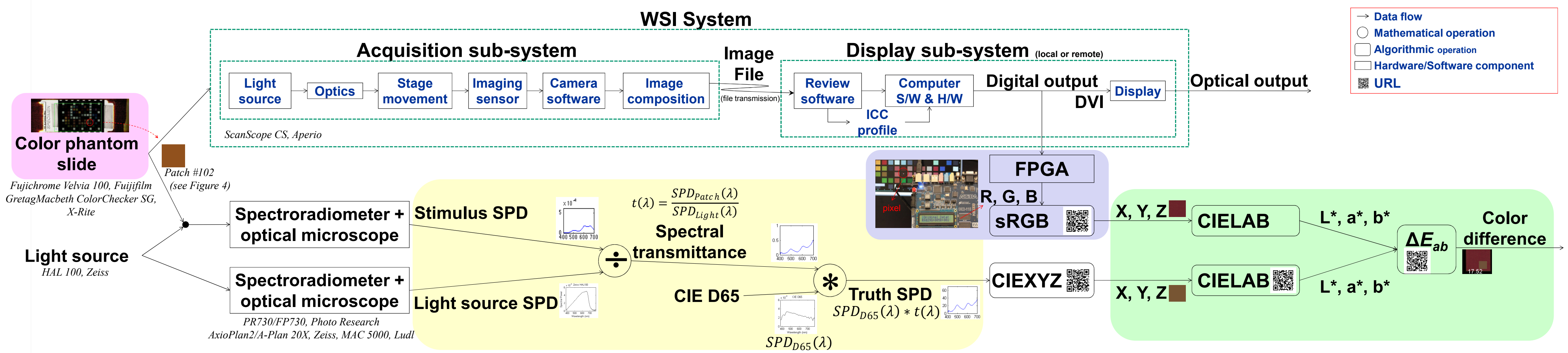


Figure 1: Data flow of the methodology. The color phantom slide goes through the upper stream, the WSI system, to obtain the digital display data, which are intercepted by an FPGA circuit board as the outcome. In the lower stream, the phantom is illuminated by a stable light source for measuring and calculating the spectral transmittance. The truth is defined as the product of the spectral transmittance and the standard CIE D65 illuminant. Finally the CIELAB color difference is calculated to indicate the color reproducibility of the WSI system. See text in the Method Section for elaboration. A color patch is used to demonstrate the SPD calculation.

Abstract

A new method for assessing color reproducibility of whole-slide imaging (WSI) systems is introduced. A color phantom is used to evaluate the difference between the input to and the output from a WSI system. The method consists of four components: (a) producing the color phantom, (b) establishing the truth of the color phantom, (c) retrieving the digital display data from the WSI system, and (d) calculating the color difference.

Introduction

Goal

To evaluate the color reproducibility of a WSI scanner, which is determined by the color difference between the output image and the ground truth of the input slide

Challenge of establishing the color truth

- Color is determined by both tissue transmittance and lighting
- Cellular structures in tissue slides are too small to measure
- Light source in optical microscopes is not standardized
- WSI assumes standard white light source

Previous work [Yagi, Diag. Path., 2011]

- Slide phantom has 3x3 filter-based patches
- Digital phantom evaluates the display sub-system only
- Evaluation Includes the display confounding effects

Our approach

- Use photographic film to produce color phantoms
- Use arbitrary light to obtain transmittance and calculate truth
- Use digital display data instead of optical measurements
- Use CIE formulas to calculate colorimetrical differences

Advantages

- Phantom with arbitrary 140+ color patches
- Light-independent, spectral transmittance-based truth
- Robust digital readout eliminating time-consuming optical measurements
- Universal, device-independent evaluation for inter-WSI system comparison

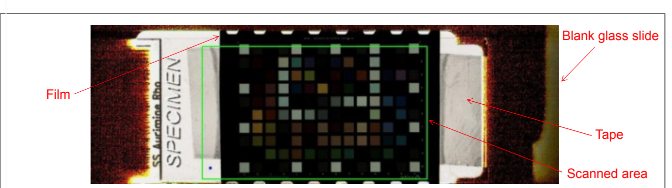


Figure 2: Snapshot of the color phantom taken by the WSI scanner.

Method (color-coded in Figure 1)

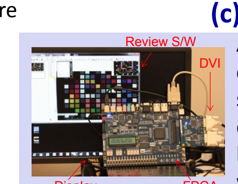
(a) Producing the color phantom

Photographic transparency film was used to photograph the color target that consists of 14x10 color patches (Figure 2). After processing by a professional lab, a well-exposed 24x36 mm² frame was chosen, trimmed and attached to a blank 1"x3" glass slide. Every color patch is large enough to cover the field of view of a 20x microscope, 1.15 mm in diameter.

(b) Establishing the color truth $Truth = \frac{SPD_{Patch}(\lambda) * SPD_{D65}(\lambda)}{SPD_{Light}(\lambda)}$

A spectroradiometer with a flexible probe was installed in a microscope with a 20x objective and a tungsten-halogen lamp. The spectral power distribution (SPD) of each color patch was measured automatically with a motorized XY-stage. The stimulus SPD was divided by the light source SPD to obtain the spectral transmittance, which was then mathematically illuminated by the standard CIE D65 illuminant to define the truth.

(c) Retrieving digital display data



Although the display is a swappable component and usually introduces considerable variability, the display interface always uses the standard sRGB color space and provides robust digital output. A custom-designed field programmable gate array (FPGA) circuit board was inserted between the computer and display to snoop the pixel values (see inset), which were then converted into the CIELAB color space.

(d) Calculating color difference

The CIE 1976 ΔE_{ab} formula was used to calculate the difference between the scanned image and the truth of the color phantom after converting into the same CIELAB color space.

Color Management

Some WSI systems use the ICC framework for color management. An ICC profile can be embedded in the image file during the acquisition phase. The review software can optionally activate the ICC profile through the operating system's color management service during the display phase.

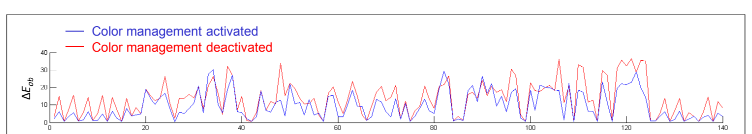


Figure 3: ΔE_{ab} color differences of the 140 color patches between the truth and the scan. Color management reduced ΔE_{ab} for 118 color patches. ΔE_{ab} is indeed the distance between two colors in the 3-dimensional CIELAB color space. The two-dimensional projection views are shown in Figure 5.

Experimental Results

The test results on a WSI system are shown in Figures 3, 4, and 5.

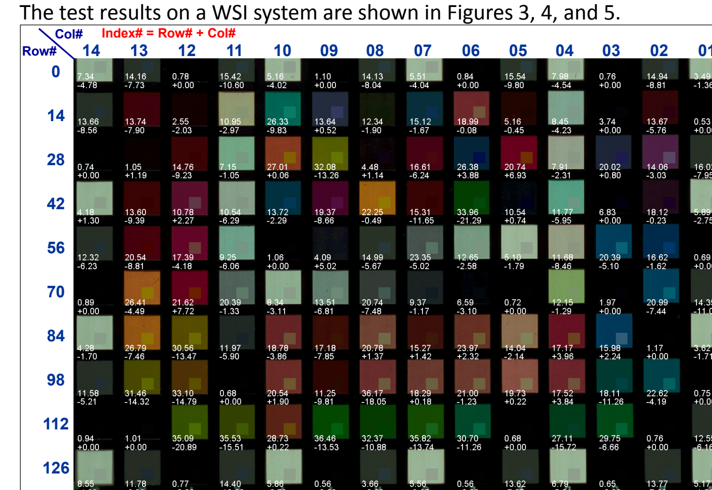


Figure 4: Visualization of the color differences. The color management-activated WSI scan is on the background superimposed by the color truth embedded in each color patch. The color difference ΔE_{ab} for each color patch is represented by two numbers – the ΔE_{ab} without color management plus the change made by the color management. Notice that brown and pink patches (e.g., #54 and #88) were scanned similarly as reddish colors. Also cyan and blue patches (e.g., #34 and #58) were scanned similarly. See Figure 5 for the trend of color differences.

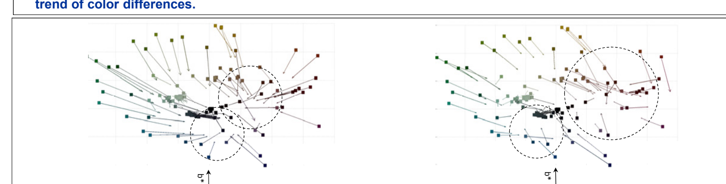


Figure 5: Color differences on the CIELAB a*-b* chromaticity plane. The x-axis (CIELAB a*) represents the transition from green (negative) to red (positive), while the y-axis (CIELAB b*) from blue (negative) to yellow (positive). The lightness information (CIELAB L*) is concealed as the z-axis. Each arrow represents a color patch. The arrowtail/arrowhead indicates the location and color of the truth/scan. The dotted circles show where the arrows converge, meaning reduced color contrast among the color patches.

Conclusions and Future Work

The experimental results show pronounced color differences for certain hues when color management is activated and even worse performance without color management. The findings suggest that color reproducibility of WSI scanners is stain-dependent and demands careful adjustments within a color management framework. For future work, the minimum color difference required for performing specific diagnostic tasks will be investigated.

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SPIE Medical Imaging 2013, Digital Pathology, Poster 8676-23
February 10-11, 2013, Lake Buena Vista, FL, USA
Ver. 8

Acknowledgement

The authors thank Dr. Stephen Hewitt (NIH/NCI) for loaning the optical microscope system and Drs. Rodney Rouse and Katherine Shea (FDA/CDER) for sharing the WSI system. This study was supported in part by a grant from the Critical Path Initiative at the Food and Drug Administration and by an appointment to the Research Participation Program at CDRH administered by ORISE through an interagency agreement between DOE and FDA.