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OpenDICE: an Open License Solution for Imaging Quality Assessment

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Abstract

In this paper we present our recent software development, OpenDICE, as an open license solution for digital imaging quality assessment. We matched the FADGI (Federal Agencies Digitization Guidelines Initiative) specifications to construct the digital imaging quality assessment criteria in OpenDICE, which evaluates the image quality in three major categories: tonescale, color accuracy, and resolution analysis. The software currently supports two commercially available targets, and will support new targets under development. We developed two versions of the software, one for individual image quality analysis which offers user interaction to control the assessment criteria, and the other for batch image processing which collects the assessment results for statistical analysis.

1. Introduction

The original DICE program was developed under contract to the Library of Congress, and has become an indispensable tool for quality management within the cultural heritage community. However, the license for the underlying software environment is expensive and has limited the use of the system to larger institutions. OpenDICE has been developed by the Library of Congress to provide the same functionality as DICE, without the licensing costs.

Cultural heritage digitization centers worldwide rely on imaging quality assessment to insure the accuracy and consistency of their digitization efforts. A variety of standards have been established to assess different quality factors of imaging products, including resolution [1, 2, 3], intensity (e.g., OECF) [4] and color [5, 6] accuracy, noise [7], dynamic range [8], sharpness [1, 9], and geometric distortion [10], just to name a few. Such assessment is generally implemented by scanning or taking a picture of a standard target board, for example, Macbeth ColorChecker SG chart[1] or GoldenThread™ (also called DICE) target[2] (see Figure 1), then deriving the quality factor values. For example, color accuracy can be measured by computing the difference (e.g., ΔE2000 [11, 12]) between the target image values with the pre-measured color patch values provided by the manufacturers, while the image sharpness can be evaluated by the modulation transfer function (MTF) [13, 14] or the spatial frequency response (SFR) [15].

For image quality assessment, software such as DICE, delt.ae[3], iQ-Analyzer™ [4], and Imatest™ [5] is available for general applications. Additionally, there is application-specific software bound with different manufactures' imaging devices, for example, Imaging Gauge™ [6], Picture Quality Analyser (PQA™) [7], and DXO™ Analyser [8]. In this paper we focus only on general applications. iQ-Analyzer™ and Imatest™ provide a rather comprehensive series of products and services to support all the major image quality evaluations, including both target charts and corresponding software. However, they do not relate directly to FADGI guidance. DICE was developed to follow the FADGI criteria, and became the de facto standard software in digital preservation and archiving. Delt.ae provides similar analysis as DICE, and it is free for public use. However, the resulting report is oversimplified with only patch color measurements (RGB and CIE LAB values). Users can only see the assessment details only by pointing to individual patches. Moreover, the technical support of the software is limited.

***Figure 1**. Examples of targets for device color accuracy assessment. Left: ColorChecker SG chart; Right: GoldenThread™ target.*

[1] ColorChecker Digital SG. http://xritephoto.com/ph_product_overview.aspx?ID=938

[2] Image Science Associates. http://www.imagescienceassociates.com/

[3] Delt.ae – Online image quality assessment. http://delt.ae

[4] iQ-Analyzer. http://www.image-engineering.de/products/software/376-iq-analyzer/

[5] Imatest | Image Quality Testing Software & Test Charts. http://www.imatest.com/

[6] Imaging Gauge Software Test System. https://www.appliedimage.com/products/imaging-gauge-software-test-system

[7] Picture Quality Analyzers | Tektronix. http://www.tek.com/picture-quality-analyzer

[8] Image Quality | www.dxo.com. http://www.dxo.com/us/image-quality

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Using DICE as a starting point, we added new features to OpenDICE. Specifically, we developed two versions of the software: one for individual image quality assessment with enhanced user interaction capability; the other version for semi-automated batch image processing, which handles a large set of collections. Both versions can export detailed assessment results, which may be applied for further statistical analysis to characterize the device performance over time. Similar to DICE™, we roughly classify the assessment criteria according to three categories: tonescale, color accuracy, and resolution. We developed the software with modularized architecture. The modules are independent of each other and each one focuses only on a specific criterion. Such architecture enables an easily maintained system, and individual modules can be upgraded without affecting the others.

This paper is organized as follows. Section 2 briefly introduces the background of image quality assessment. Section 3 presents the OpenDICE software interface and functional modules. Examples of assessment results on a ColorChecker SG chart and a GoldenThread™ target are presented in Section 4. We draw conclusions in Section 5.

2. Background

Imaging quality assessment is usually implemented by locating different reference regions on target boards, deriving the predefined features on those regions, and evaluating the features according to the preselected criteria. Here we briefly describe the assessment principle for different image quality factors.

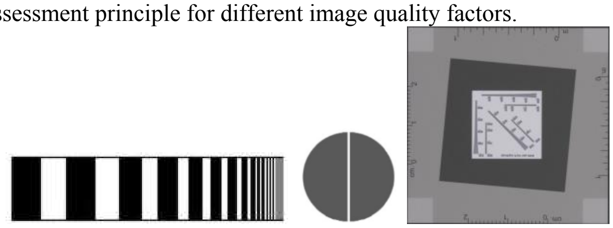

***Figure 2**. Examples of targets for MTF/SFR analysis. From left to right: sinusoidal, slit and slanted edge targets.*

One of the most important factors of imaging resolution analysis is image sharpness assessment [16], which determines the amount of detail that an imaging system can reproduce. It is usually measured by the MTF or SFR, both of which characterize the system responses with respect to different signal frequencies, e.g., the response (MTF magnitude) at low, middle and high frequencies of the input signal. In practice we may either directly measure the system responses to periodic patterns (e.g., sine pattern bars) of different frequencies, or we can conduct a frequency transform (e.g., Fourier transform) to derive the system response on an input signal indirectly. The input signal can be derived as the *edge spread function* (ESF) using slanted edges or the *line spread function* (LSF) using slit targets. Figure 2 shows examples of the above three targets (test charts). Indirect methods are often used due to their simple implementation, and the slant edges are always included in common target boards for the SFR computation. For example, the GoldenThread™ target consists of five slant edge regions at the four corners and the board center, as shown in Figure 1. An excellent review on those approaches may be seen in [13].

Another important image quality factor is color accuracy, i.e., the color difference between the imaging results of different patches and the corresponding ground truth (i.e., true color of the patches). Here the regions of interest (ROI) are a set of color and gray patches on the target boards. For example, the ColorChecker SG chart consists of 140 color and gray patches that are arranged as a 2D array on the chart, and the GoldenThread™ target includes 30 color and gray patches at the top and bottom center of the chart, see Figure 1. Color accuracy is generally measured by computing the CIE ΔE2000 value between the imaging results and the ground truth. In particular, after the ROI identification, the patch color values are generally measured in RGB space, which are then converted to the CIE LAB space for the ΔE2000 computation. The conversion is usually implemented with the transformation matrix that is embedded in the CIE ICC color profile of the image. The ground truth can be either obtained from the target chart manufacturer or measured by users with devices such as colorimeters, spectrodensitometers, or spectrophotometers following the ISO standards [5, 17, 18]. For example, we may choose the illuminants (e.g., D50 or D65), data format (spectral response or tristimulus colors), and output color space (e.g., XYZ or LAB) with the device user interface. However, different devices produce different measurements at different times on the same target patches. Even the same device will produce different measurements over time on the same target. This introduces both intra- and inter-variations on the measurements. To address this issue, statistics-based approaches may be applied to optimally estimate the ground truth [19, 20].

Besides the resolution and color accuracy, other major image quality factors include the OECF (opto-electronic conversion function), white balance, illuminance uniformity, and noise. The OECF curve measures the relationship between the input light level (reflectance) and the output signal level (density), which provides the gamma correction curve for an imaging device. Thus it characterizes the accuracy of an imaging device in conducting such transformation. White balance measures the illuminance effect and imaging color artifacts on objects. With prior knowledge of the object color, we can adjust the RGB components to derive the true color of the object, which is then applied to the whole imaging process to achieve the correct color balance. Illuminance uniformity and noise measure the peak intensity difference and variance (or standard deviation), respectively. The assumption here is the homogeneous regions should be smooth with minimalintensity variations. The above factors are always evaluated on gray patches of the target charts.

3. OpenDICE Modules

As stated in the Introduction, OpenDICE adopts a modularized structure, and the functional modules are as follows.

1. **ROI Identification**. This module extracts all the feature regions for subsequent analysis. It also detects and rejects any significant distortion and rotation greater than the predefined threshold values. The module locates all the ROIs through specific feature detection on the targets. For example, it

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identifies the black circles on the GoldenThread™ target using image processing algorithm (Hough transform), based on which the relative locations of the ROIs may be detected individually. The features for the ColorChecker SG chart are the white crosses at the four corners, which may be detected by template matching. In case of any inaccurate or unsatisfactory results, users may change the size and location of the corresponding rectangles. Moreover, for very large size images, OpenDICE provides a manual selection option in order to detect the ROIs more accurately and faster. It allows the user to identify the four corners of the chart on the input image, according to which the software locates the ROIs automatically.

2. **Resolution analysis**. Following ISO 12233 [1], the SFR can be computed in three steps: 1) locating the slanted edge regions; 2) computing the corresponding ESF (the profile across the edges) and LSF (the derivative of the ESF); and 3) calculating the Fourier transform of the LSF to derive the SFR. The module derives the SFR curves for all the edge regions (with slanted edges) on the GoldenThread™ target, and then it computes the sampling efficiency values for each region and each color channel. The results are compared with the preselected FADGI criteria for performance assessment. This module also computes the sampling frequency in both vertical and horizontal directions, which are then compared with the scanner setting.
3. **Color accuracy assessment**. For each color and gray patch on the target chart, the module computes the ΔE2000 between the imaging results and the true color. The image color values are first converted from the RGB space to the CIE LAB space using the embedded ICC profile, which are then used for the ΔE2000 computation. Simple statistics of ΔE2000, and the error of individual components (L^* and a^*b^*) are also reported. In addition, this module computes color registration error among the color channels. Specifically, it fits the slant edges in the edge regions for RGB channels separately, and then compute the difference of the three intercept values as the registration error, e.g., G - B, G - R, and B - R. FADGI criteria are applied to assess the above results.
4. **OECF curve**. This module draws the OECF curves for the RGB channels of the target gray patches, i.e., the center 12 patches (E5:J6) of the ColorChecker SG chart and the patches #10-#21 of the GoldenThread™ target. The input is the density (D) values of the patches, which can be either measured by spectrodensitometers or derived by statistics-based approaches like the CIE LAB values. The desired intensity value can be computed as:

$$I = 255 \cdot \left(10^{-\frac{D}{\gamma}} - b \right) / a \,,$$

where a, b, and γ are the gain, offset, and gamma parameters input from the user. The default values are 1, 0, and 2.2. By comparing these expected intensity values with the imaging results, the module computes the tone response error. The software also provides the interface for users to change the parameter settings and view the curve changes in real time. The error band defined by the FADGI Guidelines is presented as a reference for the parameter adjustment.

5. **White balance**. For each gray patch (12 patches for each target), this module computes the difference of average color values, i.e., B - R, G - R, and G - B. Ideally, the difference should be zero.
6. **Illuminance uniformity**. This module computes the average intensity and RGB values for the light gray patches at five different locations on the GoldenThread™ target. Then the uniformity metric is computed as (max$I$ – min$I$) / mean$I$ for the RGB channels across all the light gray patches.
7. **Noise**. With the 12 gray patches for each target, the noise measurement is computed as the standard deviation of the RGB channels separately.
8. **Import and export**. This module provides the interface for user input of all the parameter settings, including the selection of target (GoldenThread™ or ColorChecker SG), FADGI criterion level, target profile, single image or image folder (for batch processing version). The target profile consists of the true CIE LAB and density values for all the target patches. Finally, the export function allows users to save all the assessment results after a number of trials with different parameter settings, e.g., a, b, and γ values. The assessment results of pass or fail (of the FADGI criteria) are also reported. For the batch processing version, users cannot change the settings once the processing starts.

4. OpenDICE Implementation

The Library of Congress developed OpenDICE using the Matlab™ 2015a programming environment. OpenDICE was compiled as stand-alone software for distribution. The software interface is shown in Figure 3, where the user may select target and FADGI criteria for assessment, as well as load the profile and image. Once the image is loaded, the ROIs are automatically detected, as shown in Figure 4. If the detection results are not satisfactory, users may manually change the size and location of the rectangles on each region. The Manual Detection checkbox provides another option for more accurate and faster ROI detection, which is especially beneficial for very large size images.

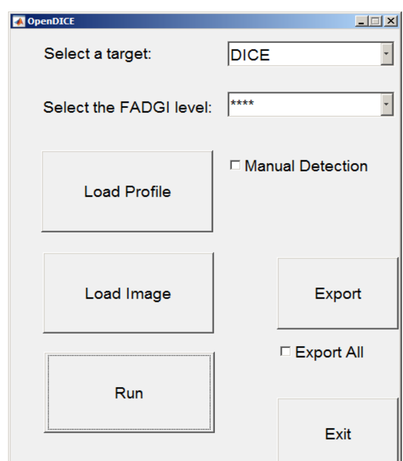

Figure 3. *OpenDICE Interface.*

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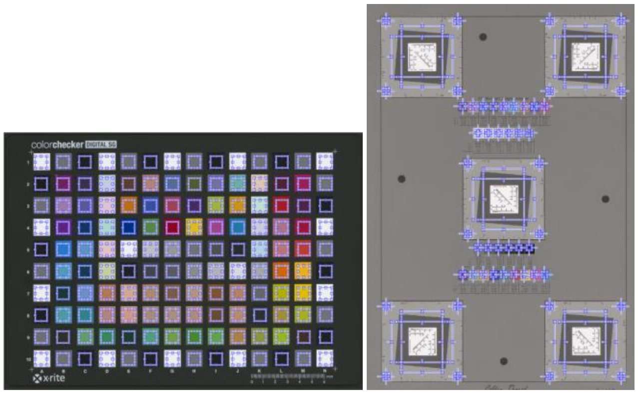


__Figure 4__. Examples of ROI detection by OpenDICE.

After the review of ROI detection results, users may click the Run button to conduct the assessment. The assessment results are presented in three windows: resolution analysis, tonescale analysis, and color accuracy assessment, each of which consists of a set of tabs for detail presentation.

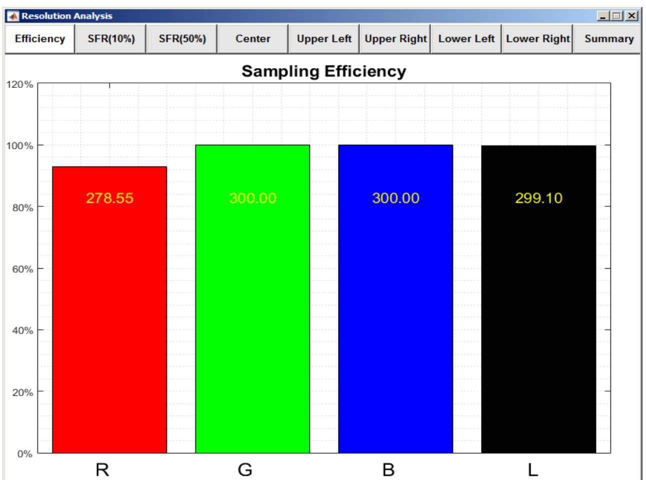
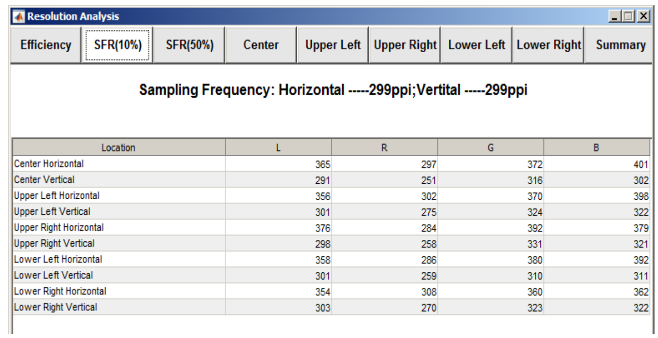


***Figure 5.** Example of Sampling Efficiency tab in the resolution analysis window.*

An example of the resolution analysis window is shown in Figures 5-8, which applies only to GoldenThread™ targets. Figure 5 shows the sampling efficiency tab in the window, which provides the RGB average sampling efficiency values of all the edge regions. It can be seen that the sampling efficiency is 100% for the green and blue channels, and around 95% for the red channel. Figure 6 lists the sampling frequency values measured at 10% MTF magnitude for different locations. These values specifically indicate the measurements at high frequencies, and an example at the image center location can be seen in the SFR curves in Figure 7. It can be clearly seen that the green, blue, and luminance channels obtain high sampling frequency (> Nyquist frequency, i.e., the vertical solid line) at 10% MTF magnitude (the bottom horizontal solid line). Similar results can be obtained for the 50% MTF magnitude (the center horizontal solid line in Figure 7), which mainly measures the sampling frequency at middle frequency range. Figure 7 shows the SFR curves of the target center edge regions. The pink line segments show the corresponding FADGI criteria according to the user selection. For example, at the high frequency segment, only the red and luminance SFR curves intersect the pink segments, which indicate a pass for these two curves at high frequency. On the other hand, only the luminance SFR curve falls between the two pink segments at 50% MTF magnitude, thus only the luminance channel passes the FADGI criterion at middle frequency. In figure 8 we show an example of the summary tab of the resolution analysis window. This tab presents all the numeric values of the measurements and the assessment results based on the selected FADGI criteria, including the sampling frequency at vertical and horizontal directions, and the middle and high frequency SFR measurements at different locations of the target image.



Resolution Analysis

Efficiency | SFR(10%) | SFR(50%) | Center | Upper Left | Upper Right | Lower Left | Lower Right | Summary

Sampling Frequency: Horizontal -----299ppi;Vertital -----299ppi

Location	L	R	G	B
Center Horizontal	365	297	372	401
Center Vertical	291	251	316	302
Upper Left Horizontal	356	302	370	398
Upper Left Vertical	301	275	324	322
Upper Right Horizontal	376	284	392	379
Upper Right Vertical	298	258	331	321
Lower Left Horizontal	358	286	380	392
Lower Left Vertical	301	259	310	311
Lower Right Horizontal	354	308	360	362
Lower Right Vertical	303	270	323	322

***Figure 6.** Example of SFR (10%) tab in the resolution analysis window.*

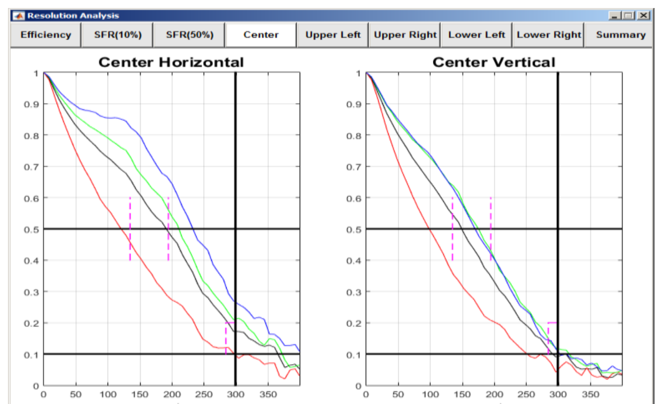


***Figure 7.** Example of SFR curve tab in the resolution analysis window.*

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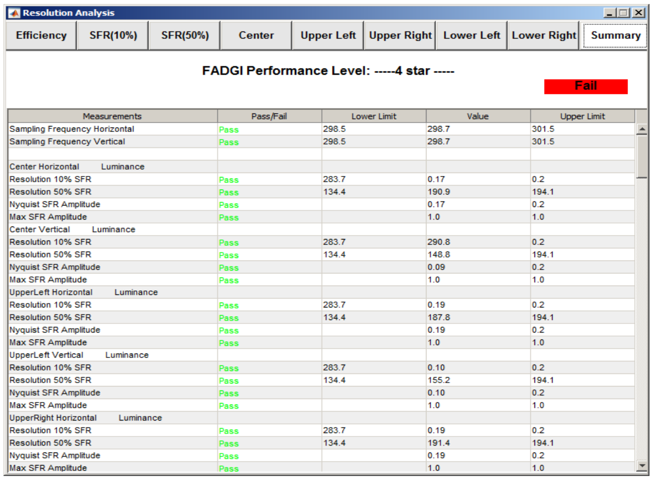

Figure 8. *Example of Summary tab in the resolution analysis window.*

Figures 9-12 present the four tabs in the color accuracy assessment window. Figure 9 compares the measured luminance and the true luminance (aim) for all the patches. Figure 10 lists the ΔE2000 and ΔE2000 (a^*b^*) for all the target patches, and the FADGI criteria that are highlighted by the horizontal lines, i.e., the maximum upper limit and the mean upper limit. Figure 11 shows the color registration error (G - B, G - R, and B - R) for both vertical and horizontal edge regions. Note that this assessment does not apply to the ColorChecker SG chart. Similar to Figure 8, Figure 12 presents the detailed measurements and assessment results, which may also be exported as a user report.

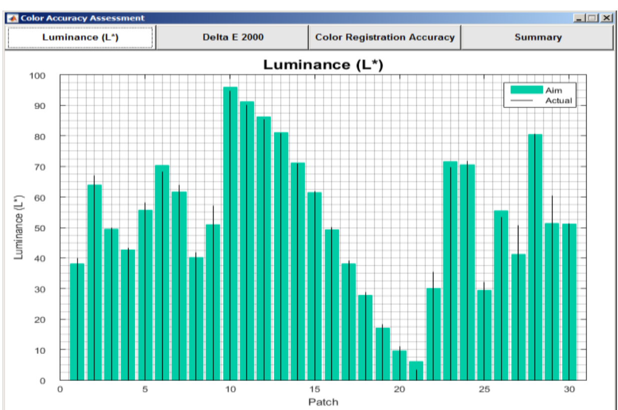

Figure 9. *Example of Luminance tab in the color accuracy assessment window.*

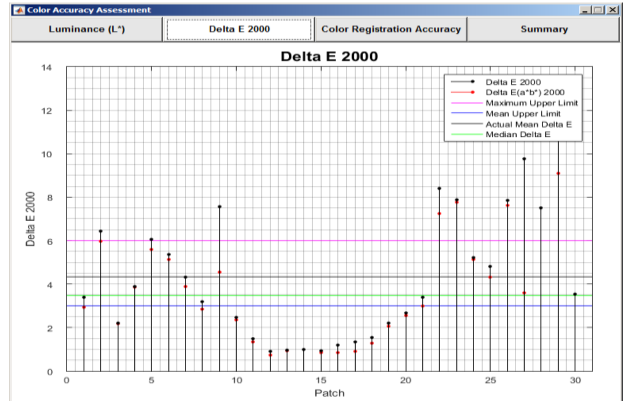

Figure 10. *Example of ΔE2000 tab in the color accuracy assessment window.*

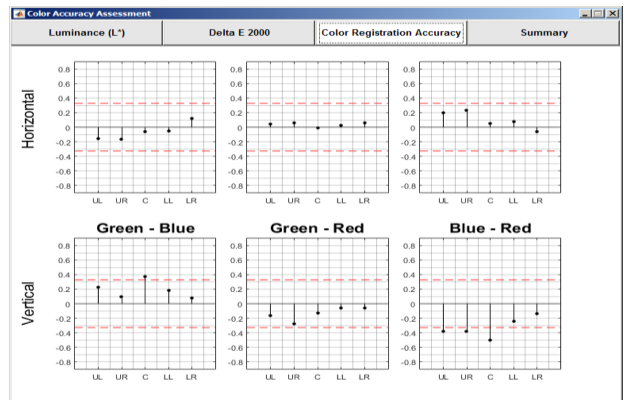

Figure 11. *Example of Color Registration tab in the color accuracy assessment window.*

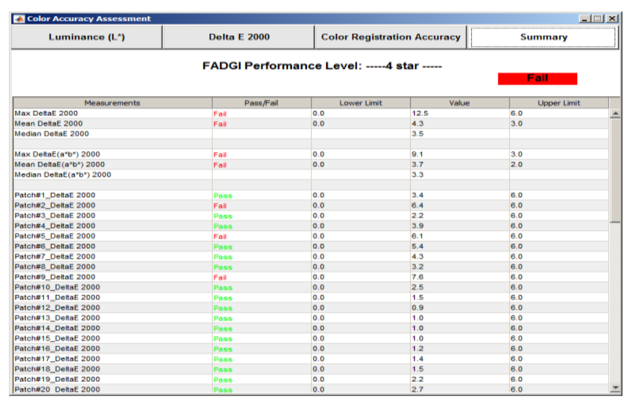

Figure 12. *Example of Summary tab in the color accuracy assessment window.*

Figures 13-18 present the six tabs in the tonescale analysis window. Figure 13 shows the interface that allows user input of the gamma, gain, and offset, based on which the OECF curves of the RGB channels are drawn in real time. The pink curves show the FADGI criterion range, i.e., the OECF curves falling inside this range pass the test. Figure 14 shows the OECF error, with the FADGI criteria as the reference. Again, the error inside the pink ranges passes the assessment. Similarly, Figures 15 and 17 present the white balance error and noise, using the FADGI criteria (indicated as pink lines) as the reference. Figure 16 lists the

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average RGB and illuminance values on which the peak difference is computed. At last, Figure 18 presents all the detailed tonescale measurements and assessment results, which can also be exported as an assessment report.

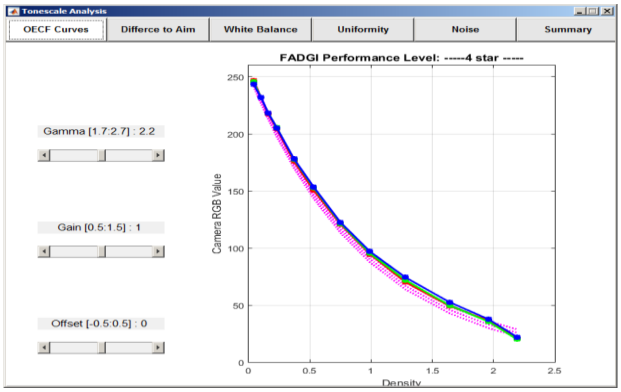


Figure 13. *Example of OECF Curves tab in the tonescale analysis window.*

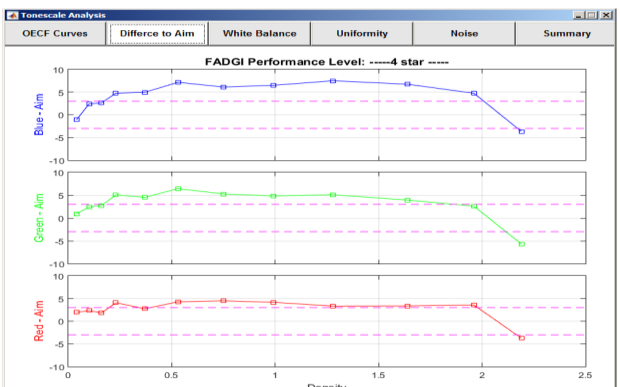


Figure 14. *Example of OECF error tab in the tonescale analysis window.*

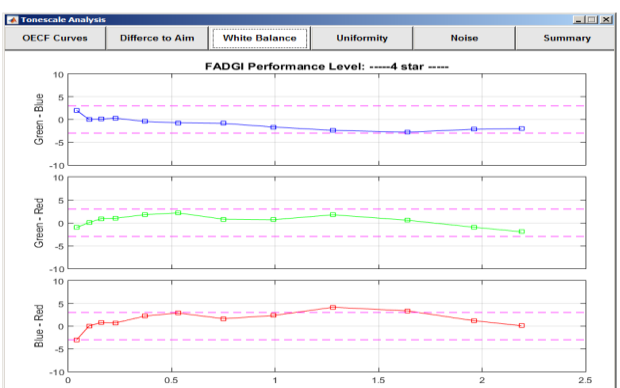
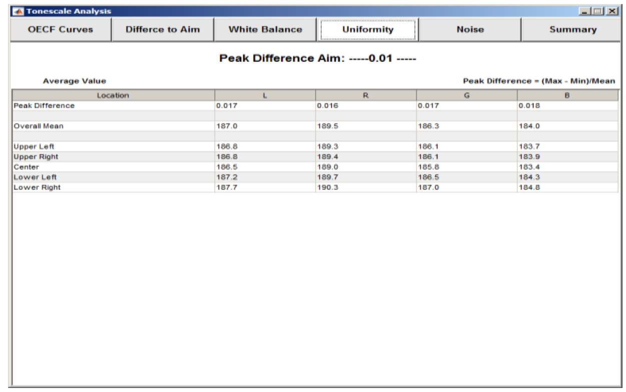


Figure 15. *Example of White Balance tab in the tonescale analysis window.*



Peak Difference Aim: -----0.01 -----

Average Value

Peak Difference = (Max - Min)/Mean

Location	L	R	G	B
Peak Difference	0.017	0.016	0.017	0.018
Overall Mean	187.0	189.5	186.3	184.0
Upper Left	186.8	189.3	186.1	183.7
Upper Right	186.8	189.4	186.1	183.9
Center	186.5	189.0	185.8	183.4
Lower Left	187.2	189.7	186.5	184.3
Lower Right	187.7	190.3	187.0	184.8

Figure 16. *Example of Uniformity tab in the tonescale analysis window.*

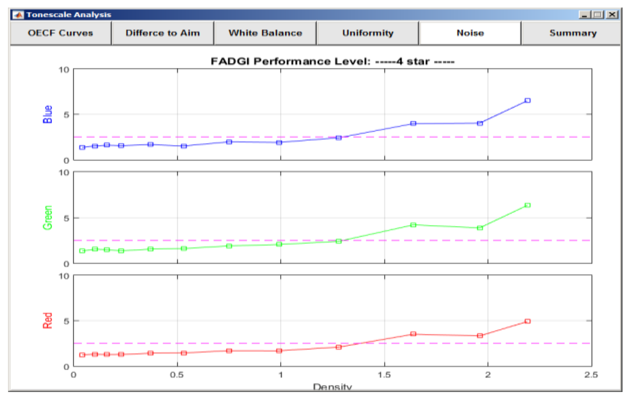
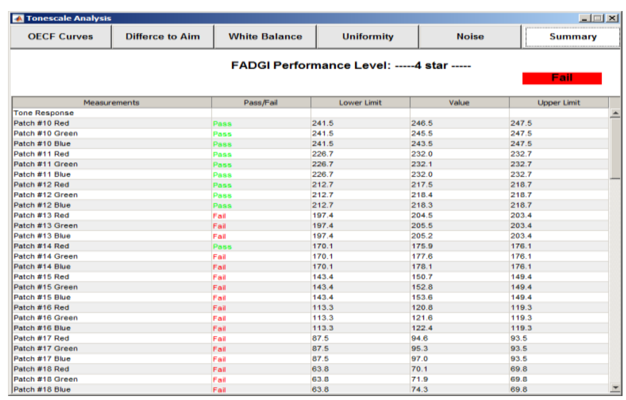


Figure 17. *Example of Noise tab in the tonescale analysis window.*



FADGI Performance Level: -----4 star -----

Fail

Measurements	Pass/Fail	Lower Limit	Value	Upper Limit
Tone Response				
Patch #10 Red	Pass	241.5	246.5	247.5
Patch #10 Green	Pass	241.5	245.5	247.5
Patch #10 Blue	Pass	241.5	243.5	247.5
Patch #11 Red	Pass	226.7	232.0	232.7
Patch #11 Green	Pass	226.7	232.1	232.7
Patch #11 Blue	Pass	226.7	232.0	232.7
Patch #12 Red	Pass	212.7	217.5	218.7
Patch #12 Green	Pass	212.7	218.4	218.7
Patch #12 Blue	Pass	212.7	218.3	218.7
Patch #13 Red	Fail	197.4	204.5	203.4
Patch #13 Green	Fail	197.4	205.5	203.4
Patch #13 Blue	Fail	197.4	205.2	203.4
Patch #14 Red	Pass	170.1	175.9	176.1
Patch #14 Green	Fail	170.1	177.6	176.1
Patch #14 Blue	Fail	170.1	178.1	176.1
Patch #15 Red	Fail	143.4	150.7	149.4
Patch #15 Green	Fail	143.4	152.8	149.4
Patch #15 Blue	Fail	143.4	153.6	149.4
Patch #16 Red	Fail	113.3	120.8	119.3
Patch #16 Green	Fail	113.3	121.6	119.3
Patch #16 Blue	Fail	113.3	122.4	119.3
Patch #17 Red	Fail	87.5	94.6	93.5
Patch #17 Green	Fail	87.5	95.3	93.5
Patch #17 Blue	Fail	87.5	97.0	93.5
Patch #18 Red	Fail	63.8	70.1	69.8
Patch #18 Green	Fail	63.8	71.9	69.8
Patch #18 Blue	Fail	63.8	74.3	69.8

Figure 18. *Example of Summary tab in the tonescale analysis window.*

5. Conclusion

OpenDICE is a next-generation quality assessment tool built on and compatible with the proven DICE quality management system. OpenDICE software will be available at no cost to the user, and is certified for FADGI conformance monitoring. OpenDICE provides both manual and batch target analysis and allows data export for long term process monitoring and statistical analysis.

The original DICE program established quality standards for federal agencies participating in the FADGI program, and has become the standard for cultural heritage image quality

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monitoring. OpenDICE builds on this history and provides an open license alternative to DICE. OpenDICE will be freely available by download from sites TBD once testing is complete.

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Author's Biography

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