Digital Imaging Framework

Part I – Taxonomy of Digital Imaging Performance
Part II – Evaluation and Quality Control of Digital Imaging

Introduction

As described in the Still Image Charter, a key element in our approach to developing guidelines is to describe and document a common foundation of quality metrics for investigating and evaluating digital objects created through digital imaging.

The following two-part document was developed to satisfy that need. The first part of the document provides a taxonomy of imaging performance. This hierarchical classification demonstrates the connections among related [existing] imaging characteristics, and provides context and a framework for the array of commonly used terms and the appropriate imaging standards available for the evaluation of digital image files. The second part of the document builds upon the framework set forth in Part I and provides operational metrics and criteria for evaluating digital image characteristics for purposes of investigation or, when used with specific requirements, for quality control purposes.

Future work of the Still Image Working Group will rely on this document to establish quantitative guidelines using the described derivative metrics and evaluation criteria. The actual values that will be inserted into specific imaging guidelines will depend on the content to be digitized and the objectives for digitization. A description of content and objective categories is under development by the Categories and Objectives Sub-group. This framework document, combined with specified content and objective categories, form the foundation of specific imaging guidelines that will follow.

Explanation of Document Features and Layout:
Graphical symbols used in the row labeled "Evaluative Criteria *(units)*" indicate Primary, Secondary and Tertiary measures.

- ● = Primary
- ◒ = Secondary
- ○ = Tertiary

These have meaning both across and within metrics. Across the metrics or image characteristics, they indicate the relative importance as a factor of image quality; from the highest (Primary) to the lowest (Tertiary).

The same concept applies within the measurement for a given metric. Taking SFR as an example, Max SFR gain is suggested as the Primary Measure under Sharpening, and Sign of SFR slope as a Secondary Measure. There are also two additional informational tiers included in the table. One of these provides a listing of related descriptive terms that may be more commonly known to users. The bottom-most tier provides a list of possible causes of failure related to a particular metric.

Terms may also appear as links. These terms will take the user to the Glossary of Terms for definitions of technical terms that may not be familiar to all users.

Given that this work represents Phase I of an evolving document, not all aspects of performance characteristics or methods of deriving metrics have been developed. In these cases the abbreviation “TBD” for “to be determined” will be present. These are recognized gaps in our knowledge or in our development of established procedures, and will be more fully described in a forthcoming Gap Analysis Document.

Part 1 - Taxonomy of Digital Imaging Performance

See subsequent pages for information on
definitions, candidate evaluation criteria, related descriptive terms, and failure causes

Foundation Metrics	Signal									Signal-to-Noise Ratio	Noise												
Engineering Metrics	**OECF** (Opto-Electronic Conversion Function)				**SFR** (Spatial Frequency Response)						Radiometric Distortion **NPS** (Noise Power Spectrum)						Geometric Distortion					
Derivative Metrics	***Speed / Sensitivity***	***Tone, Exposure***	***White Balance/ Neutrality***	***Color Encoding Accuracy***	*Sampling Rate*	*Resolution*	*Sharpening*	*Acutance*	*Flare*	*Depth of Focus*	*Dynamic Range*	*Total Noise*				*Chroma Noise*		*Regional (deterministic)*	*Color Misregistration (deterministic)*	*Aliasing (deterministic)*	*Spatial SFR Uniformity (deterministic)*	*Pincushion/Barrel (deterministic)*
												Temporal	*Fixed pattern*										
												Random (stochastic)	*Banding/Streaking (deterministic)*	*Defects (stochastic)*	*Non-uniformity (deterministic)*	*Color Uniformity (deterministic)*	*Color SFR Uniformity (deterministic)*					

* While imaging noise is generally considered to be of a random or stochastic granular nature (e.g., photographic film grain), it can actually take many forms. We have chosen to categorize it in both by its deterministic and stochastic behaviors.

Part II - Evaluation and Quality Control of Digital Imaging

- SIGNAL -

Engineering Metrics	OECF – Opto Electronic Conversion Function (ISO 14545) TTF – Tone Transfer Function TRC – Tone Reproduction Curve *definition* : Average large area digital response of an electronic imaging device to light stimuli			
Derivative Metrics	**Sensitivity** (ISO 12232) *definition:* The reciprocal of the amount of light necessary to achieve a desired output response.	**Tone and Exposure** *definition* : characteristic behavior of large area digital output response (count value) to spectrally neutral input stimuli (gray patch)	**White Balance/Neutrality** *definition* : equivalence of large area color channel output responses to a range of spectrally neutral input stimuli	**Color Encoding/Rendering Accuracy** *definition:* The difference between selected physically measured input colors and their intended output rendering from a given color space.
Related descriptive term	– Responsivity – Speed – Exposure Index (EI)	– Too dark/light – Under/over exposed – No shadow/highlight detail – Clipping – Contrast – Exposure Accuracy	- Color cast - Gray balance	– Over/under saturated colors – Color balance is wrong – Memory colors are not correct – Color Accuracy – Color Saturation
Evaluation Criteria *(units)* ●=Primary ◗=Secondary ○=tertiary	●: Saturation based speed *units: TBD* ◡: Noise based speed *units: TBD* ○: Exposure Index, Standard Output Sensitivity	●: Average, median, maximum or RMS deviation from aim for neutral patches of interest. *units:* Count Values, ΔL*, Density, F-stops ◡: Deviation from a reference OECF gamma value *units:* gamma (unitless)	●: Average, median, maximum, or RMS deviation from aim between color channels (R-G, R-B, G-B) for neutral patches of interest. *Units (●):* Count Values, $\Delta E_{a^*b^*}$, *Units (◡):* Delta C, Delta H	●: Average, median, maximum, or RMS deviation from aim for chromatic patches of interest *Units (●):* Count Values, Delta E (ΔE), Delta E ($\Delta E_{a^*b^*}$), *Units (◡):* Delta C, Delta H
Possible failure causes	- Inefficient imaging detector	–Auto-contrast failures –Inappropriate black/white point calibration. - Wrong gamma selection or tone aim	– Poor auto-white balance algorithm – Bad white /black point calibration – Sparse gray patch balancing – Color Balance – Strongly colored environmental surround	– Color profile tweaked for preference – Wrong color profile intent – Wrong color profile chosen/embedded – Color profile assumptions inconsistent with practice (i.e. lighting quality, gamma, intent, etc.) – Environmental : highly chromatic color surround/clothing

- SIGNAL -

Engineering Metric	SFR - Spatial Frequency Response – (ISO 12233, ISO 16067-1, ISO 16067-2, ISO 15524) MTF – Modulation Transfer Function *definition* : A spatial frequency descriptor of an imaging system's ability to maintain the relative contrast of input stimuli					
Derivative Metrics	**Sampling Rate** *Definition:* The reciprocal of the center-to-center distance between closest adjacent pixels. The number of samples per unit distance.	**Resolution** *Definition: An* imaging system's ability to resolve finely spaced detail. The level of spatial detail that can resolved in an image	**Sharpening** *Definition* :Amplification of the SFR by means of image processing to achieve sharper appearing images	**Acutance** *Definition*: An objective SFR based metric that is used as a correlate to perceived image sharpness.	**Flare** *Definition:* a skirty or wide spreading of light.	**Depth of Focus** *Definition: The distance along the optical axis that remains within acceptable focus.*
Related descriptive term	- Megapixels - Dots per inch (dpi) - Pixels per inch (ppi) - Sampling frequency	– Blurred – Soft – Sharp – In/Out of focus – Spherical aberration – Spatial detail	– Oversharpening (haloing, garish edges) – Snap – Edgy, Sharp, Crisp – Edge enhancement - Unsharp masking	- Sharp	– Low contrast – Hazy – Ghosting - Veiling flare - Glare - Integrating cavity effect (ICE)	- Depth of field - Circle of confusion - Focus tolerance - Hyperfocal distance
Evaluation Criteria (*units)* ●=Primary ◗=Secondary ○=tertiary	●: The number of captured or delivered pixels per unit distance in both the horizontal and vertical dimensions *units:* dots-per-inch, pixels-per-inch	●: 10% sampling efficiency based on Luminance SFR *units:* (unit less) ●: Min/Max 10% spatial frequency limits of Luminance SFR *units:* dpi, cycles/mm ◗: Min/Max 50% spatial frequency limits of Luminance SFR *units:* dpi, cycles/mm	●: Max SFR gain *units:* % SFR response ◗: Sign of SFR slope *units :* positive/negative slope value	●: Area under the SFR as weighted by an appropriately chosen visual contrast function. *units:* TBD	● % Flare - *units: (unit less)*	●: Distance along the optical axis that remains in acceptable focus *units:* inches, mm.
Possible failure causes	- Poor calibration technique - Wrong choice of units at calibration	- Poor (auto) focus - Poor optics - Poor choice of aperture stop - Mechanical vibration - Over aggressive noise control	- Over aggressive sharpening settings - Insufficient signal to amplify - Thinking that if a little is *good* then *more* must be better.	- Optical performance exceeds sampling rate	- Dirty lens - Light source directed into lens - Poor quality lens - Stray light	- Poor F-number choice

– NOISE –

Engineering Metric	– Radiometric Distortion – *definition:* The deviation of any given spatially imaged point from an aim radiant energy value relative to the input object.					
Derivative Metrics	Noise Power Spectrum (NPS) *Total Noise* *Definition* : A spatial frequency descriptor of the sources of radiometric noise of an imaging component or system				Chromatic Noise *Definition* : The inter-color channel radiometric deviations relative to an identified aim	
Derivative Metrics	Temporal Noise	Fixed Pattern Noise			Color Uniformity (deterministic) *Definition* : A difference in large area uniformity/shading between color channels	Color SFR uniformity (deterministic) *Definition:* The differential spread of light between color channels.
	Random (stochastic) *Definition* : The root mean square deviation (std. deviation) of both temporal and fixed pattern noise for a single color channel	Banding/ Streaking (deterministic) *Definition* : One dimensional patterns	Defects (stochastic) *Definition* : point or clusters of defective or poorly corrected pixels	Non-Uniformity/ Shading (deterministic) *Definition:* A deviation in the effective illumination over a capture device's field of view; usually with lower illumination near the field's outer extent.		
Related descriptive term	- Temporal noise - Grain - Shot noise - Read noise - White noise	- Stripes - Banding - Streaking	- Hot, Cold, or Dead Pixels - Wounded Pixels - Blinkers	- Vignetting - Relative illumination	- Rainbows	– Colored edges – Color Bleed – Fringing
Evaluation Criteria (*units*) ●=Primary ◗=Secondary ○=tertiary	●: RMS deviation of pixel values in terms of selected metric(i.e., counts, density, Luminance) over an identified region of interest *units:* counts, density, Luminance	●: The relative amount of variance or noise power that a selected spatial frequency band contributes to the total noise. *units:* TBD	●: The number or size of defects per unit sensor area. *units:* # of defects/unit sensor area	●: The percent deviation of several large area luminance measurements over the field of view relative to the average of those measurements. *units:* % Luminance difference (unit less)	●: The percent deviation of several large area chroma measurements over the field of view relative to the average of those chroma measurements. *units:* % chroma difference (unit less)	●: The difference in SFR response between selected color channels. *units:* % deviation in SFR response relative to the highest measured SFR (unit less)
Possible failure causes	- Aggressive digital signal amplification or processing - High ISO speed selection - High throughput workflows	- Poor sensor calibration - dust/dirt on linear array sensor - poor sensor calibration	- dust on sensor - poor sensor fabrication hygiene - poor sensor calibration	- poorly designed optics - non-uniform lighting	- Chief ray angle (CRA) mismatch between optics and sensor - Non-uniform color coatings at sensor fabrication.	- Poor optical design or performance

- NOISE –

Engineering Metric	– Geometric/Spatial Distortion – *definition:* The deviation of any imaged point from its intended or aim spatial position relative to the input object.				
Derivative Metrics	<u>Field height diagram</u> <u>(deterministic)</u> *Definition:* A change in magnification of an imaged object as a function of field position.	<u>Regional</u> <u>(deterministic)</u> *Definition* :A locally varying deviation in intended spatial position of an imaged object	<u>Color Misregistration</u> <u>(deterministic)</u> *Definition:* color-to-color spatial dislocation of otherwise spatially coincident color features of an imaged object.	<u>Aliasing</u> <u>(deterministic)</u> *Definition* : A sampling effect that leads to spatial frequencies being falsely interpreted as other spatial frequencies	<u>Spatial SFR uniformity (luminance)</u> <u>(deterministic)</u> *Definition:* A difference in luminance SFR as a function of optical field position
Related descriptive term	– Pincushion – Barrel – TV distortion – Field Curvature – Skew – Keystoning	- Wobble - Jitter	- Colored edges - Chromatic aberration - Lateral chromatic error(LCE)	– Jaggies – Moiré – Pixelization – Potential for aliasing	- Blurred or soft look near corners of image - Spherical Aberration - Coma
Evaluation Criteria (*units)* ●=Primary ◗=Secondary ○=tertiary Derivative Metrics	●: The amount of distortion derived from a selected position on a field distortion diagram (typical for single shot devices) *units:* % distortion (unit less) ◡: Percent difference in the number of pixels in the Horizontal and vertical directions for a square object dimensions.(Typical for scanning backs or linear scan devices) *units:* % distortion (unit less)	●: RMS deviation in terms of pixels or distance relative to an extended linear feature *units:* rms deviation in pixels or distance relative to an identified linear feature. *units*: pixels, distance	●: The amount of spatial dislocation between any two selected color channels. *units:* # pixels, # inches, # mm	●: SFR response at half-sampling frequency. *units:* % SFR response ○: Area under the SFR beyond the half-sampling frequency. *units: TBD*	◡: % deviation in SFR response at a selected spatial frequency across the field of view *units: RMS SFR response* *Min/Max SFR response*
Possible failure causes	- Poorly designed optics - Mismatched sampling rates in the horizontal and vertical directions	- Mechanical fluctuations or dislocations in the movement of an imaging sensor.	- Poor optical design or assembly - Poor color algorithm reconstruction in RGB single shot cameras. - Poor optical alignment.	- Optical performance exceeds the sampling frequency capabilities. - Lack of optical pre-filtering	- Poor optical design or assembly

- NOISE -

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