Use of a Multispectral Camera System and Very Small, Comprehensive "Micropatch" Test Targets for Full Tonal Scale Colorimetric Evaluation of the Permanence of Digitally-Printed Color and B&W Photographs

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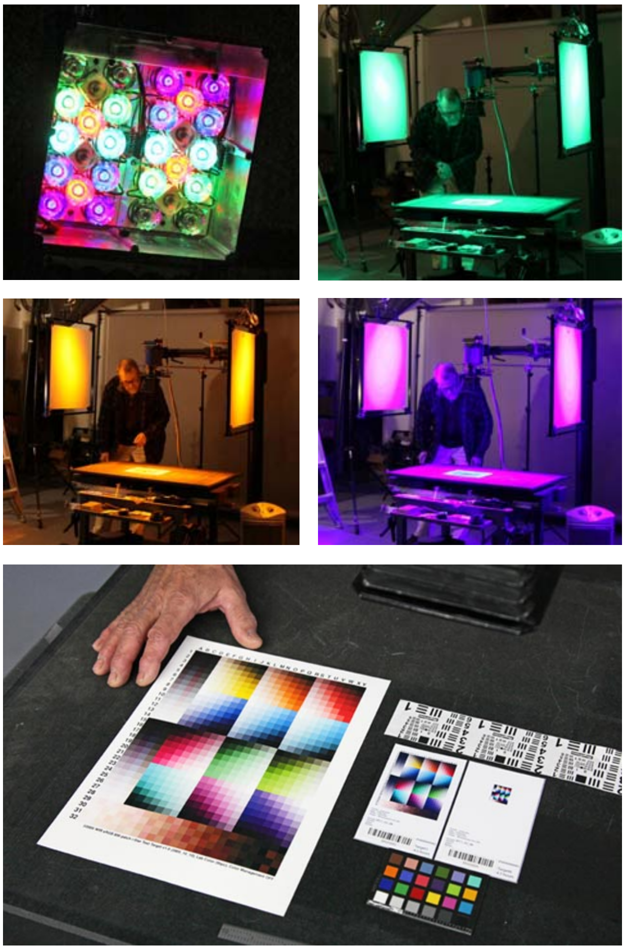
Abstract: The paper describes the use of the MegaVision EV Multispectral Camera and image processing software together with very small, full tonal scale test targets with 800 or more "micropatches." The test target includes human skin colors and large sets of neutral and near-neutral patches for the full tonal scale colorimetric evaluation of the permanence of digitally-printed color and monochrome photographs, and other images. Compared with the large test targets now routinely employed by printer, ink, toner, and paper manufacturers, as well as by independent test laboratories, the very small size of the "micropatch" test targets means that approximately *ten to fifteen times more* test targets can be accommodated in a xenon arc test unit, humidity- and temperature-controlled Arrhenius oven, or in a precision-controlled ozone test chamber. Degradation of optical brighteners can also be measured and quantified. In medium- and large-scale permanence testing laboratories, substantial cost reductions can be achieved in equipment costs – and in operational and maintenance expenses. Sample measurement time can be reduced significantly because multiple targets – including those with very large numbers of patches – can be measured at the same time. Because the camera makes no physical contact with the sample surface, unlimited numbers of measurements can be made with no risk of damage to test targets. Taken together, the procedures described here will provide more meaningful image permanence test data, both faster and at far lower cost than current methods allow. In addition, test equipment energy requirements and environmental impacts are reduced.

Introduction

Nearly all digital cameras – and most other color imaging systems available today – rely on three color filters to define the colors recorded by the system. Such systems typically record the nominal red, green, and blue values reflected from, emitted by, or transmitted through an array of points on a scene illuminated with broadband (white) light by passing the light through filters placed between the scene and the recording sensor. Color accuracy limitations of such tri-color imaging systems are well known.

When an imaging scene or object remains stationary for the duration of the imaging process, it is possible to significantly improve spectral resolution by sequentially capturing images where each captured image records a single narrow wavelength

Fig. 1 Ken Boydston (left), president and head of R&D at MegaVision, Inc., and Richard Chang with the MegaVision EV high-resolution multispectral camera and image analysis system at the company's headquarters facility in Santa Barbara, California.



Henry Wilhelm (6)

Fig. 2 Illumination from thirteen or more narrow wavelength LED's is used in a darkened room for sequential exposures with the MegaVision camera. Shown above is a standard 800-patch WIR iStar image permanence test target printed on 8.5 x 11-inch photo paper together with two reduced-size "micropatch" WIR iStar test targets.

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band of light from the scene. Capturing a series of images sequentially enables recording the image in as many spectral bands as desired, with no loss of spatial resolution.

MegaVision has developed a spectral imaging system that employs a monochrome area sensor array (Kodak KAF-3900 39 megapixel CCD array with a file size of 78 Mbytes/color at 16 bits per wavelength recorded); files are saved in uncompressed RAW format. Image capture time is about 4 seconds per frame, with a 13-band image capture requiring from 1 to 3 minutes.

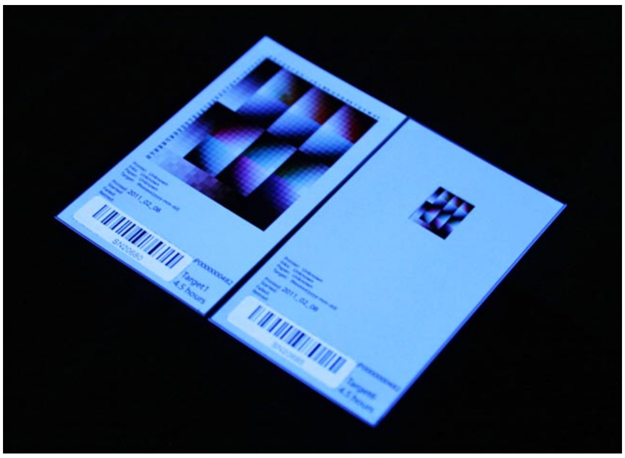
The MegaVision system uses narrow-band LED's, ranging from near UV to IR, in place of white light as the illuminant (nominally covering the 350–1000nm range of silicon detectors).[1] This arrangement improves by one or more orders of magnitude the efficacy of the light energy illuminating the scene (important, for example, where damage to delicate museum objects from light exposure is a concern) and eliminates the many problems associated with changeable filters in the optical path. Seven of the nominally thirteen (or more) spectral bands cover the visible range; additional spectral bands, including in the UV and IR regions, can be employed if desired.

The LED illumination system was developed and integrated by Equipoise Imaging, and MegaVision typically includes 50,000-hour life LED's with up to 13 specific wavelengths, including:

UV: 365nm
Visible: 445, 470, 505, 530, 570, 617, 625nm
Infrared: 700, 735, 780, 870, 940, 1050nm

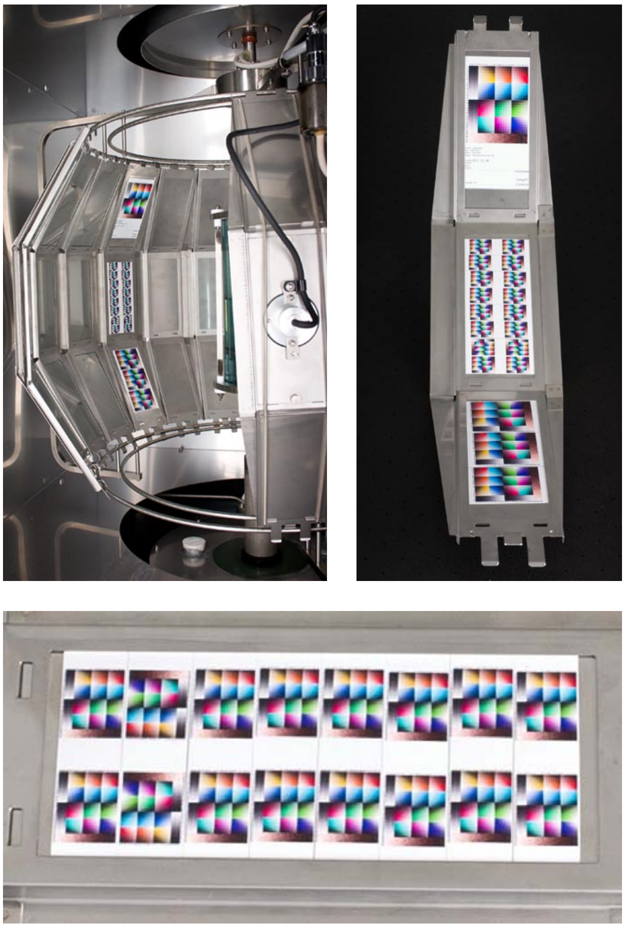
To date, the MegaVision EV multispectral camera has primarily been used in the cultural heritage field, including making extremely accurate reproductions of manuscripts and works of art. The camera is being used for imaging historical documents at the Library of Congress in Washington, D.C., including drafts of the United States Declaration of Independence.[2] The camera is also being employed by the Israel Antiquities Authority in Jerusalem <www.antiquities.org.il> for high-resolution, multispectral imaging of the 2,000 year-old Dead Sea Scrolls.[3]

The MegaVision EV multispectral camera is fitted with a specially designed 120mm f4.0 UV-VIS-IR hyperspectral lens that is apochromatic over the range of wavelengths from 350 to 1000nm. For the initial experimental work with the WIR iStar and WIR v3.0 test targets reported in this paper, the working distance was set at about 1 meter to image a scene area of approximately 35 x 26 cm. MegaVision's EV multispectral system relies on external measurements of color targets for its calibration. Typically, a color target that includes a number of colors



Henry Wilhelm (1)

Fig. 3 Presence and/or degradation of fluorescing optical brighteners (OBA's) can be measured and quantified with the MegaVision multispectral camera system. Samples are illuminated with LEDs that emit in the UV region at 365nm. The camera lens is fitted with a computer-controlled filter wheel with sequential red, green, and blue filters. This provides a way to measure not only loss of fluorescent brightener activity resulting from prolonged exposure to light, heat, or other causes, but also changes in the spectral composition of the visible light emitted by a brightener in the visible spectrum.



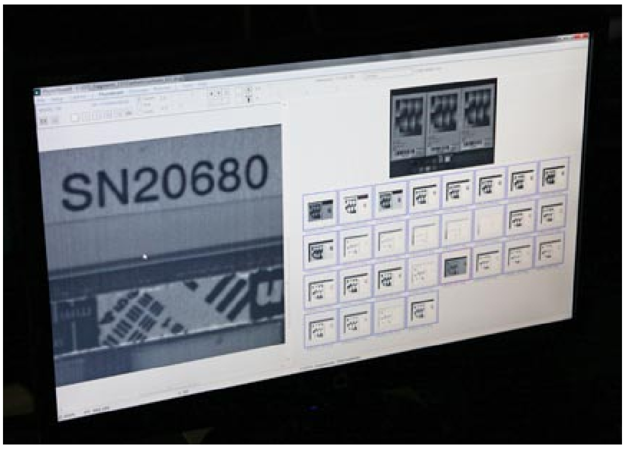
Barbara C. Stahl (3)

Fig. 4 Three different sizes of 800-patch WIR iStar "micropatch" test targets placed in a Suga SX75F accelerated xenon arc unit at Wilhelm Imaging Research.[11] A standard Suga 5.6 x 13.6 cm test sample holder can accommodate as many as sixteen "micropatch" 15 x 19 mm 800-patch WIR iStar targets in each of its three sections. Made by Suga Test Instruments Co. Ltd. in Japan, the Suga SX75F xenon unit employs dual refrigeration systems to cool the high-intensity xenon arc lamp and to control the chamber air temperature. The unit is equipped with soda-lime glass and L-37 filters to simulate the spectral power distribution of indirect daylight through window glass. The unit is fitted with dual infrared filters which help to control the desired aim sample surface temperature at 23°C, and the circulating air at the sample surface at 60% RH.

over a reasonable color range – such as an X-Rite ColorChecker Classic reference target – is measured on a spectrophotometer and these measurements, together with knowledge of the spectral illumination bands, provide the basis of calibration. MegaVision PhotoShoot software uses the calibration data as input to directly derive CIE L*a*b* (1976 D50) color images from the spectral stack of monochrome images captured under the chosen visible illuminant bands.

Like a spectrophotometer, the EV system also employs a neutral (usually white) target as a means of regularly testing and adjusting its values to compensate for small changes in the illuminants and response. Using neutral reference targets such as Labsphere Spectralon Reflectance Standards, whose reflectance properties are defined by the polymer itself, can provide repeatability over a much longer time period than the life of the imaging and measurement system itself.

The surface size of a scene imaged by a high-resolution digital camera at a reasonable resolution (e.g., 300–800 ppi) can be a large fraction of a square meter. Uniformly lighting such a large surface can be difficult, yet very high uniformity is required to meet the requirements of spectral reflectance measurements in many applications. To enable highly accurate measurements over a reasonably-sized surface, MegaVision's PhotoShoot software employs flat field correction. This correction uses images of a



Henry Wilhelm (1)

Fig. 5 Software developed by MegaVision handles data collection and analysis of the spectral stacks of the individual monochrome images obtained from exposures at each selected wavelength, and provides a way to compare the spectral data sets from each of the measurements made during the course of an accelerated image permanence test.

surface of known uniform reflectance captured under the same illumination conditions in which images of the target scene are captured. This correction also compensates for non-uniform optical response (lens fall off) and non-uniform sensor response. The correction does not require a known reflectance of the flat field surface; however, it must be uniform, reasonably bright, and have similar surface specular properties to the target scene surface.

It is, of course, challenging to obtain measurements with good traceability to NIST standards. However, for evaluating the permanence of inkjet, color silver halide, thermal dye transfer, and prints made with other photographic color imaging systems, measurement repeatability is usually more important than measurement accuracy.

The stability of well-designed LED lighting systems and CCD image arrays, together with regular use of scene-based reflectance target standards, can enable a multispectral imaging system to supplant and, in many ways, improve upon results from point sample instruments as a means of measuring the performance of color reproduction media.

An X-Rite ColorChecker Classic color target is an example of a suitable color reference source. The target is measured on a GretagMacbeth Spectrolino/Spectroscan spectrophotometer using X-Rite's Measure Tool, which is one of the applications in X-Rite's ProfileMaker 5 software. Measure Tool can output measured data as CIE L*a*b* (CIELAB) values.

The MegaVision EV system's PhotoShoot software derives CIE L*a*b* values directly from the six (or more) color bands in the visible region.

MegaVision's ImageSampler application enables sampling a rectangular array of color samples in an image and outputting the sample values in a standard spectrophotometer output format. This software enables MegaVision's EV camera to output spectral data in a manner similar to that of traditional spectrophotometers, with the added advantage that large arrays of multiple test samples can be rapidly measured.

Applications in Image Permanence Testing

For image permanence evaluation applications, test target images are sampled and the resulting text files are input to the X-Rite ProfileMaker Measure Tool "compare" application, which calculates, tabulates, and graphically displays ΔE values and statistics between two sets of test targets. Samples for each of the target images are compared and referenced against target values of the larger samples, which have individual patches of sufficient size to be measured on a GretagMacbeth Spectrolino/Spectroscan spectrophotometer. Target sample measurements can also be imported into Microsoft Excel in spreadsheet format for further manipulation and analysis.

The high-resolution multispectral camera system can image very small test targets consisting of large numbers (800 or more) of very small patches of specific colors. The minimum size of each color patch is limited only by the size and distribution of the ink drops or toner dots from a specific inkjet, liquid or dye toner electrophotographic system, dye-sub, silver-halide, or traditional offset printing system. A conventional spectrophotometer, such as the Gretag Spectrolino, may require a minimum patch size of 8 x 8 mm for repeated, reliable measurements.

With the MegaVision EV camera, depending on the image structure of the particular print system, patch sizes can be as small as 0.6 mm. For example, the 800-patch WIR iStar test target[4] developed by Wilhelm Imaging Research measures 18 x 24 cm, and is printed on an A4 or 8.5x11-inch US letter-size sheet. The WIR iStar target maps 12 hues with varying lightness and chroma, plus neutrals, near-neutrals, and skintone colors over the full tonal gradient and color gamut of the sRGB color space.

With the multispectral camera, the size of the 800-patch WIR iStar target can be reduced to perhaps only 1.5 x 1.9 cm, thus potentially enabling more than 100 separate 800-patch test targets to fit in the same space required by just one conventional 800-patch WIR iStar target. The theoretical and practical limits for how small an individual test patch can be are currently being

Table 1 – Target Size and Individual Patch Dimensions for WIR Image Permanence Test Targets

WIR iStar v1.0 Colorimetric Full Tonal Scale + Human Skin Colors Print Permanence Test Target (800 Patches)					
Target Size	Width (mm)	Height (mm)	No. of Columns	No. of Rows	Patch Size (mm)
Current Size	188	240	25	32	7.5
Reduced Size No. 1	51.5	66	25	32	2.6
Reduced Size No. 2	44	56	25	32	1.8
Reduced Size No. 3	37	47	25	32	1.5
Reduced Size No. 4	29.5	37.5	25	32	1.2
Reduced Size No. 5	22	28	25	32	0.9
Reduced Size No. 6	15	19	25	32	0.6

WIR v3.0 Traditional Densitometric Print Permanence Test Target (45 Patches x 3 Replicates = 135 Total Patches)					
Target Size	Width (mm)	Height (mm)	No. of Columns	No. of Rows	Patch Size (mm)
Current Size	72	120	9	15	8
Reduced Size No. 1	33	54	9	15	3.6
Reduced Size No. 2	27	45	9	15	3
Reduced Size No. 3	37	36	9	15	2.4
Reduced Size No. 4	16.5	27	9	15	1.8
Reduced Size No. 5	11	18	9	15	1.2
Reduced Size No. 6	5.5	9	9	15	0.6

studied. The size limit is in part determined by the dot size, pixel dimensions, driver and firmware settings, and other characteristics of each type of printing system.

Summary

There are significant theoretical and practical advantages in the use of the MegaVision EV Multispectral Camera System for image permanence testing:

• Very small-size test targets, which allows large numbers of test targets to be accommodated in a single xenon arc test chamber, resulting in substantial cost savings, in the expense of the costly test equipment itself, in energy costs, xenon lamp replacement costs, and other operational expenses. There will be correspondingly large cost savings with ozone test chambers, humidity- and temperature-controlled Arrhenius ovens, etc.

• The multispectral camera system can be used to record changes in portraits, landscape photographs, and other pictorial images in the course of accelerated fading tests. The images captured by the camera are digitally segmented into large numbers of defined pixel blocks for measurement and evaluation.

• The multispectral camera system can also image large-size test samples that may be required in stability testing of materials intended for large outdoor display applications, for example.

• The camera system can easily handle thick, rigid substrates in both small and large sizes, and with any surface properties.

• In accelerated image stability tests, each test sample will likely be measured ten or more times in the course of a test. With traditional spectrophotometers and traditional test targets, a significant amount of time is required each time a target is measured. The image resolution of the MegaVision EV multispectral camera is sufficient to capture ten or more test targets at the same time, with each target having 800 or more individual patches. The total time required to make separate exposures of a target with 13 different wavelengths is approximately 1 minute.

• Presence of fluorescing optical brighteners (OBA's) and their degradation (loss of activity) over time can be measured and quantified with the MegaVision EV multispectral camera system. Data from both the UV and IR bands provided by the MegaVision camera and analysis system can be used to help identify, characterize, and date both color and B&W print materials.

• The cost savings provided by small test targets in the operation of accelerated image stability test equipment and the speed of measurements makes it practical and economical to use the 800-patch WIR iStar test target[6] with large numbers of colors, including human skintone colors[5] and neutral and near-neutral colors, which encompass the full tonal scale. This in turn will achieve much improved full-tonal scale colorimetric evaluation of color fading,[4] changes in color balance, and the gradual development of yellowish stain.[6] The results much better correlate with human visual perception than is possible with the current industry practice of performing image permanence evaluations based on simplistic test targets that consist of only a limited number of color patches – without skintone colors included – and which are measured with RGB densitometry at only two or three density levels plus d-min.[7-10]

• In addition to the described limitations, current methods cannot evaluate fading and color shifts in human skintone colors, they cannot directly measure and evaluate changes in orange, red, green, and blue inks. Finally, current methods are not adequate for evaluating subtle color shifts and tone-scale/contrast changes with the monochrome images of fine art B&W prints, especially in delicate highlight and near-highlight regions.[7]

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11) Super Xenon Fade Meter Model SX75F, which provides sample plane light intensity of up to 100 klux, is equipped with independent lamp and test chamber refrigeration systems and dual IR filters to control sample temperature. Suga Test Instruments Co., Ltd., 5-4-14, Shinjuku, Shinjuku-ku, Tokyo 160-0022, Japan; tel: 81-3-3354-5241; fax: 81-3-3354-5275; <www.sugatest.co.jp>.

Author Biography

Henry Wilhelm was a founding member of the Photographic Materials Group of the American Institute for Conservation of Historic and Artistic Works. In 1978, he was one of the founding members of American National Standards Institute Subcommittee IT9-3 (now incorporated into ISO and known as ISO Working Group 5/Task Group 3 [WG-5/TG-3]), which is responsible for developing standardized accelerated test methods and specifications for the permanence of color photographs and digital print materials.

Wilhelm has served as Secretary of the ISO group since 1984 and he presently serves with Yoshihiko Shibahara of Fujifilm Corporation in Japan as Co-Project Leader of the ISO WG-5/TG-3 Technical Subcommittee on test methods for measuring indoor light stability. Wilhelm is also an active member of the ISO task groups responsible for storage standards for color and black-and-white films and prints.

In 1995, with Carol Brower Wilhelm, Wilhelm co-founded Wilhelm Imaging Research, Inc., to conduct image permanence studies with inkjet, silver-halide, electrophotgraphic, and other imaging materials <www.wilhelm-research.com>. In 2007, he was the recipient of the PhotoImaging Manufacturers and Distributors Association (PMDA) *"2007 Lifetime Achievement Award"* for his work on the evaluation of the permanence of traditional and digital color prints and for his advocacy of very low temperature cold storage (minus 20°C [minus 4°F] at 40% RH) for the permanent preservation of black-and-white and color prints, color negatives, transparencies, and motion picture films.

In 2010, Carol and Henry Wilhelm and colleagues established a new nonprofit organization, *The Center for the Image,* to expand their research on the permanence and long-term preservation of images.

Paper by Henry Wilhelm,* Ken Boydston,**
Kabenla Armah,* and Barbara C. Stahl*
(*Wilhelm Imaging Research, Inc.)
(** MegaVision, Inc.)
entitled:

Use of a Multispectral Camera System and Very Small, Comprehensive "Micropatch" Test Targets for Full Tonal Scale Colorimetric Evaluation of the Permanence of Digitally-Printed Color and B&W Photographs

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Addenda

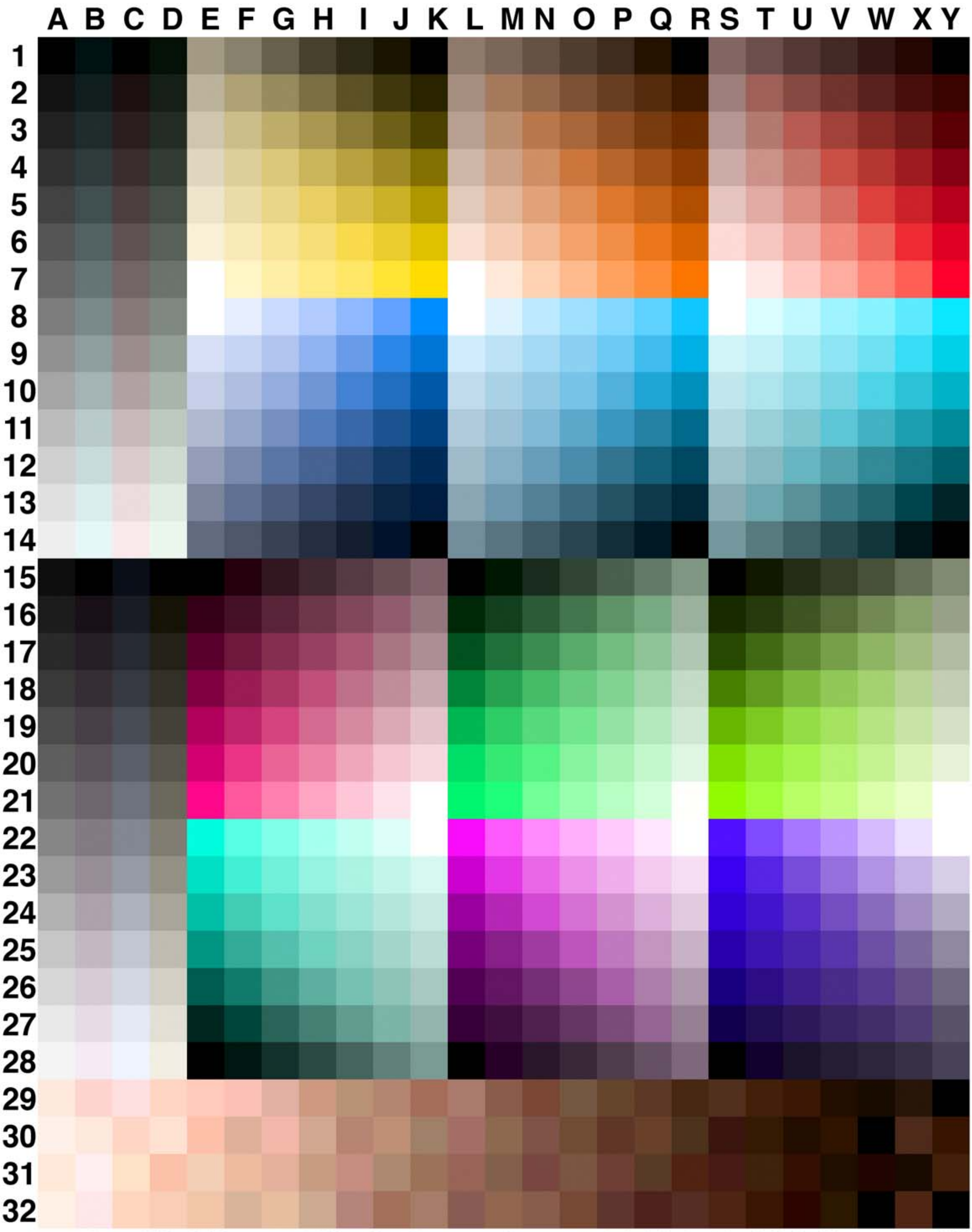
Shown on the following pages:

Full Size 800-Patch WIR iStar Test Target and Smaller Versions of the Target for Use With the MegaVision Multispectral Camera System and WIR iStar Image Change Analysis Software

and

Full Size 135-Patch "Standard" WIR v3.0 Test Target and Smaller Versions of the Target for Use With the MegaVision Multispectral Camera System and WIR Image Change and Endpoint Analysis Software

Note: These test target examples are shown here for illustrative purposes. They were not included with the paper submitted to the ISJ Imaging Conference JAPAN 2011. However, all of these images were included in the presentation given by Henry Wilhelm at "Imaging Conference JAPAN 2011" in Tokyo on June 7, 2011.



©2005 WIR sRGB 800 patch i-Star Test Target v1.0 (2005_10_10), Lab Color (8bpc), Color Management OFF

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Inks: Unknown
Paper: Unknown
Target: INxxxxx(yyyy-mm-dd)

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Started:
Failed:
Retired:

P0000000482

Sample ID:

Target1
Control

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Target: INxxxxx(yyyy-mm-dd)

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Printed: 2011_02_08
Started:
Failed:
Retired:

P0000000482

Sample ID:

Target6
Control

A magnified view of the gray patch to the right of the number 28 in the 800-patch WIR iStar test target. In the full-size iStar target, each square patch measures 7.5 mm on each side. The target was printed with a Canon imagePROGRAF iPF 8300 large-format printer using Canon LUCIA EX pigment inks. As can be seen, the ink drops are uniformly distributed and a target of greatly reduced size, with individual patch dimensions as small as 0.6 mm, can be used.

Align Here >

Printer: Unknown
Inks: Unknown
Paper: Unknown

Target: IN01873(2010-03-11)

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d-min		1	2	3	4	5	6	7	8	Neutral
Red 0.25		1	2	3	4	5	6	7	8	Yellow
Red 0.6		1	2	3	4	5	6	7	8	Magenta
Red 0.9		1	2	3	4	5	6	7	8	Cyan
Red 1.1		1	2	3	4	5	6	7	8	Skin
d-min		1	2	3	4	5	6	7	8	Neutral
Grn 0.25		1	2	3	4	5	6	7	8	Yellow
Grn 0.6		1	2	3	4	5	6	7	8	Magenta
Grn 0.9		1	2	3	4	5	6	7	8	Cyan
Grn 1.1		1	2	3	4	5	6	7	8	Skin
d-min		1	2	3	4	5	6	7	8	Neutral
Blue 0.25		1	2	3	4	5	6	7	8	Yellow
Blue 0.6		1	2	3	4	5	6	7	8	Magenta
Blue 0.9		1	2	3	4	5	6	7	8	Cyan
Blue 1.1		1	2	3	4	5	6	7	8	Skin
	d-min	0.25	0.50	0.60	0.70	0.90	1.00	1.10	d-max	

JN

Sample ID:

Started:
Failed:
Retired:

Printed:

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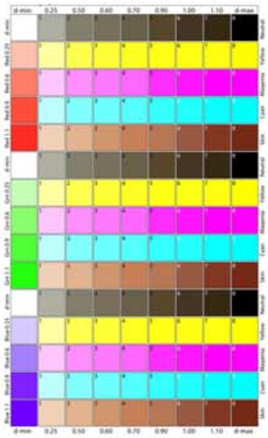

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Sample ID:

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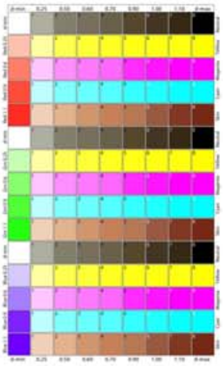

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Printed: 2011_02_08
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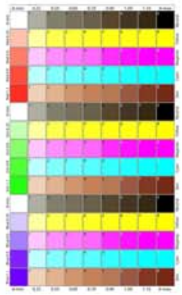
Control



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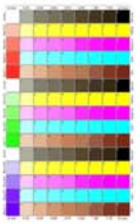
Sample ID:

Target3
Control



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Target: INxxxxx(yyyy-mm-dd)

Printed: 2011_02_08
Started:
Failed:
Retired:

P0000000482

Sample ID:

Target4
Control

Printer: Unknown
Inks: Unknown
Paper: Unknown
Target: INxxxxx(yyyy-mm-dd)

Printed: 2011_02_08
Started:
Failed:
Retired:

P0000000482

Sample ID:

Target5
Control

Printer: Unknown
Inks: Unknown
Paper: Unknown
Target: INxxxxx(yyyy-mm-dd)

Printed: 2011_02_08
Started:
Failed:
Retired:

P0000000482

Sample ID:

Target6
Control