Calibration Report

January 27th, 2004

Digital Photometric Imaging System

Model 500

Hardware S/N: C512502
Calibration S/N: DPC**502**

CE

Manufactured & Supported by:

Lumetrix Corporation

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Lumetrix Calibration Information

1 Introduction:

A series of calibration steps and tests are performed on each of the camera/lens combinations. The results of these tests are stored in software and used to provide each photometer with its own unique calibration. The details of how these calibrations are performed are provided in summary form later in this document. The photometer's serial number can be read from the cover on the camera bottom.

Calibration files for a given photometer are matched to the last three digits of that photometer's serial number. These calibration files are an integral part of the system and by default should be installed in the same directory as the programs IQConfig.exe and RT32.exe. Normally the root directory choice is C:\Program files\IQCam. If they are corrupted or not present, the photometer will not function properly and error messages will occur.

The calibration of an imaging photometer is quite a bit more complicated than a typical spot photometer. The primary reasons for this increased calibration effort are:

1) Imaging photometers capture the luminance information over a wide field of view, and must weight each area according to the spatial responsivity of the system.
2) Imaging photometers use CCD detectors, which are not perfectly linear as a function of signal (stimulus) level and are not necessarily perfectly linear as a function of exposure duration.

Note: The calibration files affect the data that is written into an image file but once written, an image file consists of a floating-point array, which contains the absolute calibration units. In this way the file, once written, becomes independent of the camera that took the original image.

Lumetrix photometers are tested and calibrated using a computer-controlled luminance standard designed and constructed by Lumetrix Corporation. The calibration of this luminance standard is referenced to a luminance / spectral radiance standard manufactured by and traceable to N.I.S.T. through:

Hoffman Engineering Corporation, 22 Omega Drive, 8 Riverbend Center P.O. Box 4430, Stamford, Connecticut 06907-0430, Tel: (203) 425-8900.

The following description details how a camera is calibrated and how the calibration is maintained within Lumetrix Corporation. The calibration procedure consists of several stages; including setting up the photometer and establishing its operational characteristics (both optical and electronic); spatial responsivity calibration; linearity calibration and absolute calibration.

The calibration computer also maintains a database of the results of calibration processes applied to each Lumetrix photometer. The calibration report that is provided with each photometer is generated from this database. This allows us to maintain records on the performance of each system -- useful for monitoring changes within individual cameras and model to model.

The photometric and/or radiometric properties of the Lumetrix photometer depend upon:

(1) The "speed" of the lens used (and iris setting) and
(2) The sample and hold duration (electronic shutter speed) of the camera.

The exposure duration and lens settings are systematically manipulated during the calibration procedure so that each combination is fully characterized and a calibration file is generated.

2.1 Dark Current Calibration of the Lumetrix Photometer:

With the lens cap on, the photometer captures an image of the CCD sensor at all of the 18 permitted exposure times. The resulting 18 images are saved and subtracted from all following images – before any other computations are done on the image.

2.2 Uniformity (or Flat Field) Calibration of the Lumetrix Imaging Photometer:

Each photometer to be calibrated is mounted on a precision kinematic mount and aimed at the 1 meter integrating sphere's output port (mounted at 90 degrees to the horizontal relative to the input port), providing the camera with a uniform luminance field. At each distinct lens setting (iris and focal length or iris and focus distance), the imaging photometer acquires an image of the uniform field. The normalized values of this image are saved as the flat field correction file (xxx.ffc). One of these .ffc files is weighted with every acquisition to ensure normalized spatial responsivity.

Depending on the lens(es) there could be 15 or more flat field correction files. These files are to be installed in the root directory as RT32 and IQConfig. Selecting a measurement setup for which the .ffc file is missing will cause an error to be reported in the software.

2.3 Linearity Calibration of the Lumetrix Imaging Photometer:

For this part of the calibration Lumetrix has developed a unique computer-controlled luminance standard. This system consists of an integrating sphere, an electronically controlled light source and photometric monitoring. This system has a luminance range of 0.1 to 10,000 cd/m^2. The output of this sphere is the calibration input for the photometer. There may be lens and exposure time combinations where the imaging photometer can measure below 0.1 cd/m^2 or above 10,000 cd/m^2 (i.e. beyond the limits of direct calibration). In these cases, the photometer response is computed and is not directly verifiable by this calibration process.

The absolute calibration of the computer-controlled luminance standard is maintained through a regular comparison against a NIST-traceable luminance standard (Hoffman

Engineering Luminance Standard Model LS-65-8D).
This procedure is done by transfer from a reference spectroradiometer: Instrument Systems CAS140B (plus TOP100) spectroradiometer.

Each photometer to be calibrated is mounted on a precision kinematic mount and aimed at the computer-controlled luminance standard's output port. The calibration system then presents a series of spaced luminance steps to the camera and the camera captures an image of each step over its full range of possible exposures for each lens aperture and focal length. For example at each focus or zoom setting:

16 discrete exposures (18 max.)

x 3 iris settings

<u>x 50 luminance settings</u>

= 2400 unique measurements

In each image, 100x100 pixel array elements at the center of the image are averaged. From the luminance and photometer response data, a set of equations are generated which describe the "opto-electronic conversion function" for each camera-lens combination. The coefficients for these equations are stored in coded calibration files (with the extensions: *.cof, *.cof2, *.cfl and *.cfl2). It is required that these files are installed into the same root directory as RT32 and IQConfig.

2.4 Absolute Calibration:

Because the spectral sensitivity of a CCD imaging device is not the same as the human eye, it is necessary to alter it optically through the interposition of a "photopic correction filter". This is a spectral weighting filter that, when combined with the spectral sensitivity of the CCD chip, results in an approximation to the CIE photopic luminosity function, V_λ. This is a standardized spectral sensitivity function accepted internationally as a valid approximation to the average spectral sensitivity of the human visual system to moderate to high illumination levels, such as are typically found during daylight hours (for more information on this function, see Wyszecki and Stiles, ***Color Science*** (2nd.ed), Wiley, 1982).
Using current optical filter design technology it is possible to produce a reasonably close approximation to the CIE V_λ function by multitude of thin film depositions on a glass substrate. Where the spectral distribution of a particular light source is known, it is possible to correct the photometer reading of directly transmitted light through the use of additional scaling factors unique to each distribution.

The Lumetrix photometer system provides a method for establishing correction factors for light sources of different spectral energy distributions. A conversion scalar can be calculated for each type of illuminant such as 3200K xenon arc (daylight approximation), cool white fluorescent, warm white fluorescent, high pressure sodium, metal halide, etc... This process is carried out at the Lumetrix factory for the NIST-traceable standard CIE Illuminant A (@ 2856K), and saved as the **FACTORY SCALAR**. The procedure to change the Factory Scalar is given in section 3.1, below.

Correction factors for other light sources are setup as **USER SCALAR**s, and their setup are discussed in a later section of this document.

2.5 Absolute Photometric Calibration Verification:

The absolute photometric calibration of each **Lumetrix** photometer is verified by aiming the camera into the integrating sphere aperture of the Hoffman standard. This is done by providing the camera with a set of luminance values ranging from 0.3 cd/m^2 to >1,000 cd/m^2 in logarithmic steps and comparing the accuracy of measurement at each member of the set. The results of this verification are detailed in this calibration report.

2.6 User-defined Calibration Procedures:

The Lumetrix imaging photometer system can be calibrated to a variety of user-definable calibration standards in order to increase the measurement accuracy, validity and reliability. Operators can create a list of correction factors. Using this technique good correlation with a reference photometer or spectroradiometer can be assured for the most common light types to be measured. Using the following procedure one can change the calibration of the system.

- Measure the uniform source of interest, measure it with the reference photometer or spectroradiometer. (Take several measurements to make sure the process is repeatable and valid.)
- Compute the factor to which the Lumetrix photometer results need to be scaled by in order to be equivalent to the reference photometer or spectroradiometer.
- Input the scalar value and unique name in the scalars menu in IQConfig.exe.
- The newly defined scalars will be available when creating new measurement analyses with RT32.
- Note the factory scalar is always applied to the image as well as the selected user defined scalars.

The estimated scalar is entered into the user defined scalars window along with a unique name within the program IQConfig.exe. These user-defined scalars are now available within the user-defined analyses of RT32.exe.

This feature will be useful to ensure that the Lumetrix imaging photometer system returns measurement results will correlate with a reference instrument, be it another photometer or a spectroradiometer. The most common discrepancies occur where the light spectral distribution is not continuous, such as is found with LED's and lasers, or when the sources measured include important line spectra such as compact fluorescent lamps, mercury lamps, etc.

3.1 Periodic Verification the Lumetrix photometer Calibration:

One should periodically check the calibration of the Lumetrix photometer, and, optionally, periodically recalibrate it to your own standard where this is feasible. The simplest and most direct method for checking calibration and for recalibration is to capture an image of the output of a "traceable" luminance standard (such as the Hoffman

Standard noted above). One could also derive the luminance from a source of known luminous intensity and project the light from this source upon a diffuse reflectance standard (such as the Duraflect™ standard plate). By factoring in the distance between the source and the reflectance standard (the plate) one can compute the luminance. The absolute response of the camera can be adjusted by resetting the FACTORY SCALAR in the program IQConfig.exe. Access to the FACTORY SCALAR is done by a double right hand mouse click in the top right hand area of user-defined scalars window in IQConfig.

3.2. Checking the Lumetrix Photometer's Linearity:

Through the use of a calibrated contrast chart, one can capture an image and compare the ratio of the readings of the different panels of the gray scale. This can be done at different average intensity levels to determine the degree to which contrast readings change across the dynamic range of the Lumetrix imaging photometer. The ratio of the "white" in the gray scale of each series should maintain a constant relationship to each of the other gray values irrespective of the average intensity. Note, because of lens flare and CCD smear, accurate contrast evaluations of >1000:1 can only be done for spatially separated targets. Contact the factory, or your Lumetrix Corp. representative for more information.

References:

American National Standard - ***Nomenclature and Definitions for Illuminating Engineering*** ANSI/IES RP-16, 1986

DeCusatis, C. (ed.) ***Handbook of Applied Photometry*** Woodbury, NY: AIP Press. 1997.

McCluney, R. ***Introduction to Radiometry and Photometry*** Boston Artech House, 1994.

Lumetrix Photometer Calibration Certificate:

1. Transfer uncertainty of the Hoffman LS-65-8D Luminance/Radiance Standard:

Luminance values at 1.0, 10.0 and 100.0 and 1000.0 ft.L. are estimated to within +/- 5% of displayed luminance for the complete calibration interval of the calibration source.

The FACTORY SCALAR for CIE Illuminant A (@ 2856K) is given further on in the calibration report

2. Standard used

Hoffman LS-65-8D, S/N: 10125.

Calibration date: on Oct. 2nd, 2003.

Used time since last calibration: 33.6 hours

Absolute Luminance Standard:

These documents provide the details for the absolute calibration standard used by Lumetrix Corpration to calibrate your IQCam™ camera.

Where your application demands highly accurate absolute photometric measurements, we recommend that you acquire a similar standard and use it in a scheduled calibration / verification program.

Flat Field Verification

The spatial responsivity of the imager was calibrated against a 6 inch port on a 1 meter integrating sphere. This was repeated for many combinations of focus, focal length and iris on the lens. This process resulted in a series of calibration files in the IQCam directory called xxx.ffc.

To verify this part of the calibration, one focus and zoom setting was compared at each iris setting. In this test, the imager looks at a 1" uniform source. The imager is oriented in 9 different directions so that the uniform target exercises a different area of the detector as shown in the diagram below. The system should report the exact same luminance at all orientations. The results are tabled below:

Table1 *The luminance of nine positions at different irises for 12.5-75 mm zoom lens. Focal length was set at 30 mm. Resolution = 0.25%.*

Position / Irises	1	2	3	4	5	6	7	8	9	Max Dev
1.8	31.49	32.60	31.44	31.84	33.14	31.63	31.60	32.82	31.52	**5.4%**
2.8	32.89	32.64	32.70	32.92	32.79	32.68	32.83	32.67	32.76	**0.9%**
5.6	32.79	32.77	32.62	32.77	32.97	32.53	32.70	32.83	32.64	**1.4%**
11	33.11	33.30	33.05	32.98	33.06	33.05	33.16	32.93	33.11	**1.2%**

Table2 *The luminance of nine positions at different irises for 8 mm wide-angle lens. Focal distance was set at 100 cm. Resolution = 0.25%.*

Position / Irises	1	2	3	4	5	6	7	8	9	Max Dev
1.4	30.86	32.07	31.09	31.56	32.98	32.00	31.09	32.15	31.14	**6.9%**
2.8	32.41	33.27	32.48	32.99	33.31	33.09	32.63	33.27	32.66	**2.8%**
5.6	30.55	30.73	30.47	30.63	30.76	30.56	30.55	30.71	30.49	**0.9%**
11	32.82	33.11	32.81	32.98	33.21	32.97	32.87	33.10	32.82	**1.2%**

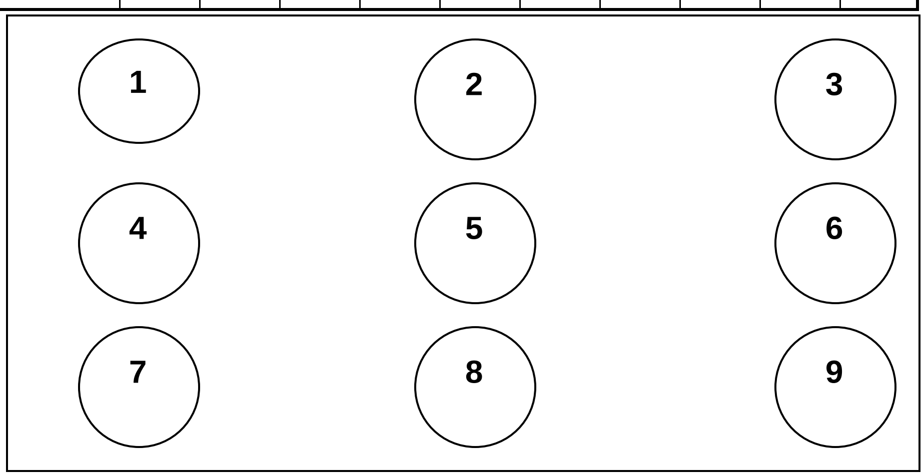

Figure 1 *shows the nine measured positions in the scene*

Accuracy Verification of Different Luminance Levels

This test assures accuracy and precision of the system over a wide luminance dynamic range.
For this test a single focal length and all possible iris settings are exposed to discrete settings on the NIST traceable luminance standard.

<u>Table3</u> *Different luminance levels were measured at different irises and a focal distance of 50 cm for 55 mm macro lens*.

Irises	Luminance Std.(cd/m2**)**	**C512502** Photometer (cd/m2)	Relative errors
1.8	0.09	0.09	0.0%
	1.28	1.28	0.0%
	10.28	10.34	0.6%
	51.30	52.39	2.1%
	100.4	100.2	-0.2%
	502.8	501.6	-0.2%
	1005.2	1019.5	1.4%
	4991.5	4971	-0.4%
2.8	0.09	0.09	0.0%
	1.28	1.32	3.1%
	10.28	10.40	1.2%
	51.30	51.61	0.6%
	100.5	98.58	1.9%
	502.8	511.3	1.7%
	1005.2	1013.2	0.9%
	4991	5015	0.4%
5.6	1.28	1.34	4.7%
	10.28	10.40	1.2%
	51.30	52.96	3.2%
	100.5	103.4	2.9%
	502.8	514.5	2.3%
	1005.2	1018.6	1.4%
	4991	5127	2.7%
11.0	1.28	1.31	2.3%
	10.28	10.48	1.9%
	51.30	52.83	3.0%
	100.5	103.5	3.0%
	502.8	512.7	2.0%
	1005.2	1018.0	1.3%
	4991	5058	1.3%

Acquisition set at 0.25% resolution
Luminance Standard: Hoffman LS-65-8D Rev-8, Serial No. 10125
Last calibrated: Oct. 2nd, 2003
Hours on lamp: 34.7 hours

Absolute Verification for All Lens Settings

This test assures the accuracy and precision of the system at a fixed luminance range using all calibrated lens combinations. These measurements are taken against a NIST traceable luminance standard operating at 2856K.

Table4 *Absolute luminance was verified for the photometer with 12.5-75 mm Zoom lens. The distance between the luminance standard and the photometer was 100 cm.*

Irises Setting	Focal length (mm)	Standard values (cd/m²)	Measured values (cd/m²)	Relative error
1.8	12.5	34.24	34.50	0.8%
	20.0	34.26	34.47	0.6%
	30.0	34.17	34.28	0.3%
	50.0	34.35	34.50	0.4%
	75.0	34.49	34.46	-0.1%
2.8	12.5	34.86	35.07	0.6%
	20.0	34.93	35.18	0.7%
	30.0	35.02	35.15	0.4%
	50.0	35.08	35.19	0.3%
	75.0	35.67	35.60	-0.2%
5.6	12.5	35.20	35.80	1.7%
	20.0	35.25	35.67	1.2%
	30.0	35.25	35.73	1.4%
	50.0	35.15	35.59	1.3%
	75.0	35.54	36.45	2.6%
11.0	12.5	35.60	36.40	2.2%
	20.0	35.61	36.26	1.8%
	30.0	35.61	36.24	1.8%
	50.0	35.61	36.03	1.2%
	75.0	35.57	36.15	1.6%

Factory scalar: 1.00
Acquisition set at 0.25% resolution
Luminance Standard: Hoffman LS-65-8D Rev – B
Serial No. 10125
Last calibrated: Oct. 2nd, 2003
Hours on lamp: 36.7 hours

Table9 *Absolute luminance was verified for the photometer with 8 mm wide-angle lens. The focal distance was set at100 cm . The distance between the luminance standard and the photometer was of 100 cm.*

Iris Setting	Focal length (mm)	Standard values (cd/m²)	Measured values (cd/m²)	Relative error
1.8	8	35.66	36.52	2.4%
2.6	8	35.67	35.60	-0.2%
5.6	8	35.67	35.76	0.3%
11.0	8	35.67	36.63	2.7%

Factory scalar: 1.00
Acquisition set at 0.25% resolution
Luminance Standard: Hoffman LS-65-8D Rev – B
Serial No. 10125
Last calibrated: Oct. 2nd, 2002
Hours on lamp: 37.0 hours.

Calibrated Lens Selections

12.5-75 mm zoom lens

Focal Length set on lens	Lens type	RT32 Lens Selction	Distance between the photometer and measured target	Iris selections	Luminance range (minimum 100 counts)
12.5 mm	Zoom	12.5	>1m	1.8, 2.8, 5.6, 11	0.00012--398000 cd/m^2
20 mm	Zoom	20	>1m	1.8, 2.8, 5.6, 11	0.00012--394000 cd/m^2
30 mm	Zoom	30	>1m	1.8, 2.8, 5.6, 11	0.00012--392000 cd/m^2
50 mm	Zoom	50	>1m	1.8, 2.8, 5.6, 11	0.00012--390000 cd/m^2
75 mm	Zoom	75	>1m	1.8, 2.8, 5.6, 11	0.00012--389000 cd/m^2

8 mm wide-angle lens

Focus setting of lens	Lens type	RT32 Lens Selction	Distance between the photometer and measured target	Iris selections	Luminance range (minimum 100 counts)
set to infinity for all working distances	Zoom	8	>0.5m	1.4, 2.8, 5.6, 11	0.00008--243000 cd/m^2

Calibrated and verified by : Aiguo Cai

Signature ____________
Date: January 27th, 2004