Advanced Test Systems for Production Testing of Cameras With Day/Night and Visible/NIR Capabilities

Tim Bryant, Alan Irwin, Paul Bryant, Steve McHugh
Santa Barbara Infrared, Inc., 30 S. Calle Cesar Chavez, Suite D, Santa Barbara, CA 93103

ABSTRACT

This paper presents the latest developments in instrumentation for military fixed and head-mounted camera test and evaluation. SBIR has completed development of a new variable contrast test system for evaluating camera day/night mode performance. The system utilizes an integrating sphere with variable, full field-of-regard background illumination combined with a collimator, controlled ambient background, a set of variably illuminated chrome-on-glass targets, and visible/NIR filters. The system employs precision azimuth and elevation motion stages to facilitate FOV size and uniformity evaluation. SBIR's IRWindows™ software provides a series of automated tests such as boresight, MTF, MRTD, FPN, pixel defects, spectral response and dynamic range/contrast. The system uses a second integrating sphere with a variable luminance control to measure FOV uniformity, individual pixel response, and automatic brightness control efficiency.

Keywords: IRWindows™, EO test & calibration, day/night mode, image intensifier, integrating sphere, fixed pattern noise, spectral response, variable optical attenuator, collimator, variable contrast ratio.

1. INTRODUCTION

The variable contrast target projector described here is specifically designed to test visible and low light level intensified CCD cameras in a production environment. The system includes a high performance collimator built into the main integrating sphere which provides uniform background illumination over the full field of regard of the camera under test. A target wheel located at the focus of the collimator accommodates a variety of chrome-on-glass targets, the clear features of which are illuminated from the rear and the chrome non-feature areas reflect the background luminance level of the main sphere from the front. Both the background luminance and target illumination can be varied over a large range. Target rear illumination is provided by an integrating sphere, directly and variably illuminated for the high luminance range and with a satellite sphere providing the variable low illumination range.

Situated between the target wheel and the target illuminator, a filter slide, accommodating spectral filters, permits the target illumination to be restricted to the visible or near infrared wavebands. A light tight enclosure is used to isolate the camera under test and the test system from local ambient lighting. The camera under test is supported by a combination azimuth and elevation motion stage, which provides the necessary angular movement of the camera to accommodate tests requiring such movement.

A computer running SBIR's IRWindows™ test software controls all system assets, provides a variety of test routines, accumulates resultant test data, and presents an interactive graphic interface to the operator.

2. OVERVIEW OF SYSTEM CONCEPT

The design of the system is based on the concept of incorporating a broadband reflective visible target projector into a large integrating sphere light source with independently variable luminance controls for target features and background. This configuration provides the ability to present variable contrast, collimated target images to the camera under test. A collimating, off-axis paraboloid optic element mounted inside a large integrating sphere projects the rear illuminated target images to the output port of the main sphere. An integrating sphere light source, (target illuminator), located

behind the target wheel provides precisely controlled, variable illumination of the features of the selected target in the wheel. The large integrating sphere provides variable, uniform background illumination covering the entire field of regard of the camera under test.

The projector system architecture is shown in Figure 1.

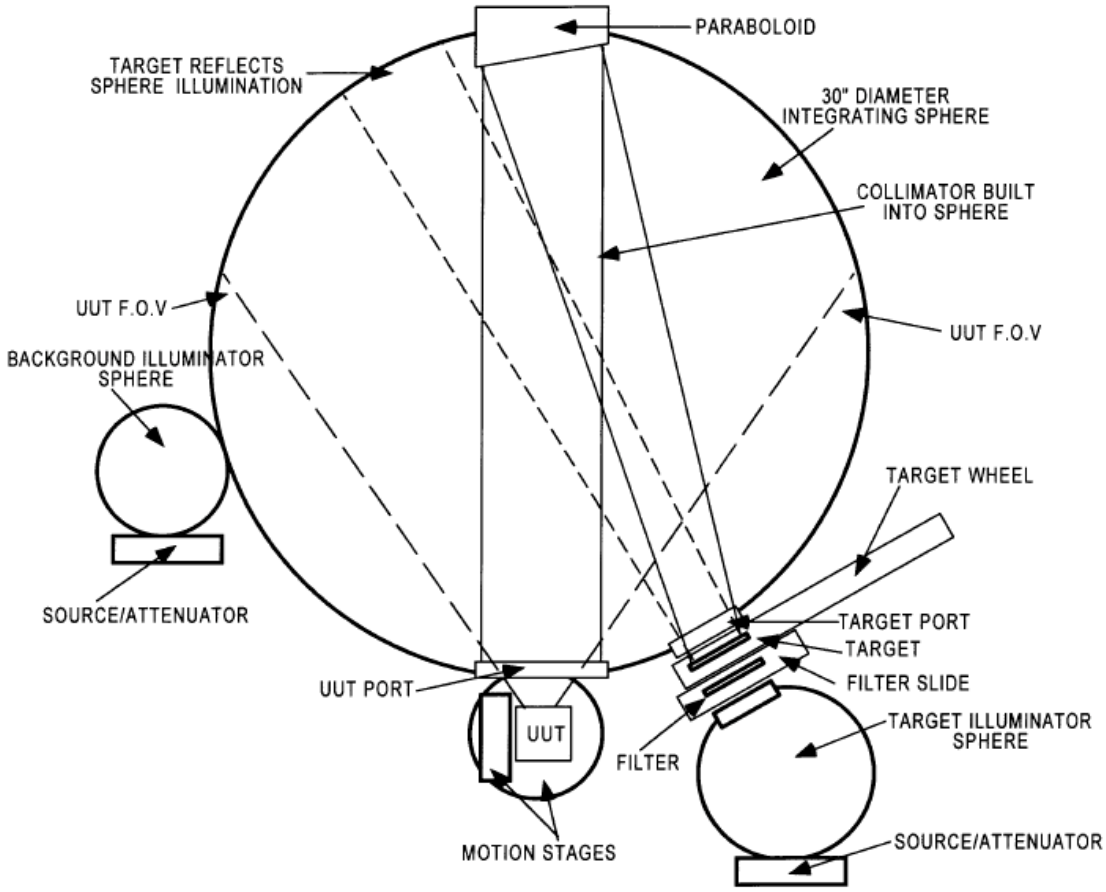

Figure 1 – System Architecture

Controllable background illumination is reflected from the front of the target and, in combination with the variable target feature illumination, (from behind the target), provides the controllable variable contrast ratio desired. This control of background and target image brightness, provides the capability for measuring many key parameters of visible sensor performance over the entire range of real-world light conditions (star light to mid-day sun).

The UUT is mounted to the elevation motion stage, which, in turn is mounted to the azimuth motion stage, the combination located in front of the exit port of the integrating sphere. Images from the projected targets are presented to the camera under test; image frames are captured by the IRWindows software and analyzed to determine camera performance. Standard evaluation tests such as boresight, field of view size, modulation transfer function (MTF), field of view uniformity and minimum resolvable contrast (MRC), are provided by the test system under the control of SBIR IRWindowsTM software.

3. SPECIFICATIONS

Target projector specifications and design parameters are listed below:

Collimator:

Clear aperture	6"
Focal length	30"
OAP surface figure	¼ wave P/V at 632 nm

Main Sphere:

Diameter	29.75 inches
Exit port	9.0 inches x 6.0 inches
Background luminance	$1.0 \times 10^{-4} – 1.0 \times 10^{-1}$ Lux, continuously variable
Color temperature	2856 K
Luminance stability	within 0.5% of set value for 10 min
Luminance uniformity	+/- 2%

Target Wheel:

Positions	12
Target field	2.0 inches
Position repeatability	< 0.001 inch
Target orientation	0, 45 and 90 degrees

Targets:

Construction	Chrome on glass, transmissive/reflective
Boresight	Pinhole, (center pinhole of matrix)
Geometry	Pinhole Matrix, (5 x 5 pinholes)
MTF	Sector step function (edge)
Dynamic range contrast	Step contrast and continuous contrast

Filter slide:

Positions	7
Filters, single	Visible, NIR, pinhole mask and neutral density
Filters, combination	Pinhole mask with NIR filter

Target Illuminator:

Output sphere diameter	8 inches
Satellite sphere	6 inches
Output port diameter	3 inches
Luminance range	$1.0 \times 10^{-4} – 1.0 \times 10^{4}$ Lux, continuously variable

UUT motion stages:

Azimuth range	± 23 degrees
Elevation range	± 18 degrees
Resolution	0.10 mrad
Position repeatability	0.15 mrad

4. SUPPORTED TESTS

The test system, under the control of SBIR IRWindows™, sets the appropriate background and target illuminator luminance levels, positions the selected filter and target, gathers data from the camera under test and processes these data in order to evaluate the UUT performance. Prior to testing, the motion stages are very accurately aligned to the optical axis of the collimator, (zero, zero position), using an auto-collimating telescope aligned to the optical axis sighting a reflective block attached to the upper motion stage, precisely located with mechanical reference.

4.1. Boresight Alignment

The target used for this test, the five-by-five pinhole matrix which consists of a five-by-five group of 0.150", (5 mrad), diameter pinholes on 0.270", (9 mrad), centers, is moved into the operating position. The target is chrome-on-glass, the pinhole features being clear substrate. Behind the target, a mask, consisting of a 0.240", (8 mrad), aperture is moved into the operating position to mask all of the target pinholes except the center pinhole. The motion stage supporting the UUT is moved to its (0,0) position, and images acquired are evaluated to determine the boresight reference of the UUT.

With the simple aperture in position behind the target, visible and NIR, (day mode), radiance is used. By placing an aperture with a NIR pass filter, the radiance is restricted to the NIR wavelengths, (night mode).

4.2. Field of View

Using the same targets and apertures as for the boresight alignment, the azimuth motion stage is moved in one direction until the target pinhole is half obscured by the edge of the field of view of the UUT. The stage is then moved in the opposite direction again until the target pinhole is half obscured by the edge of the field of view. Reviewing the azimuth position for each half obscuration, the azimuth angle of the full field of view may be determined. Similarly, the elevation angle of the full field of view may be determined by moving the elevation motion stage.

These field of view measurements may be taken in day mode or night mode, similarly as in the boresight alignment test.

4.3. Distortion

The five-by-five pinhole matrix is used (without a mask) to calculate localized distortion. Because the matrix target does not fully cover the UUT's field of view, the matrix is moved to various positions in the field of view by rotating the camera. At each position, the local distortion is calculated by comparing the geometry of the captured image to the projected geometry of the physical target.

In addition, a geometric distortion map is generated using the precision motion stages used to rotate the UUT in the collimated path. The geometric distortion at one position in the field of view is calculated by comparing the precise angles of motion to the position of the center pinhole of the matrix measured from the image. By moving the camera through a grid over the UUT's field of view, a complete distortion map can be generated.

These distortion measurements may be taken in day mode or night mode.

4.4. Camera Resolution

Taking advantage of the precise motion stages used to rotate the UUT, the camera resolution is measured using the known feature width of a precision target. By first aligning one edge of the target feature to a fixed spot in the UUT's field of view, the angular displacement necessary to align the fixed spot to the other edge of the target feature is determined using the stages. This angular displacement is compared to the known width of the target to determine the camera's measured resolution.

This measurement may be taken in day mode or night mode.

4.5. Modulation Transfer Function (MTF)

The MTF of the camera is derived from a Fourier analysis of the Edge Spread Function (ESF). A pie shaped target is presented to the UUT, and an image captured. The target has a sharp vertical edge and a sharp horizontal edge so that the ESF can be calculated either horizontally or a vertically. The ESF is then differentiated to create a Line Spread Function (LSF). A Fourier transform is applied to the LSF, generating the spectral information used to calculate the MTF.

The MTF measurement may be taken in day mode or night mode.

4.6. Dynamic Range/Contrast

A target has been constructed with 10 different contrast regions. Each region has a fixed contrast, and the 10 regions are arranged as a 2 x 5 array. When illuminated, an image from the UUT is captured, and the measurements in each contrast region are taken separately. For each region, the average measurement and the standard deviation of the measurements are calculated. By dividing the average by the standard deviation, a dynamic range for that contrast is calculated. By calculating the number of steps unique to each contrast range, the total number of steps across the entire range can be summed. This sum is reported as the dynamic range contrast.

Since the contrast from the 10 regions is relative to the overall source illumination use in the test, the same target and calculations can be used in day mode or night mode.

5. SYSTEM DESIGN

A functional block diagram of the projector system is shown in Figure 2.

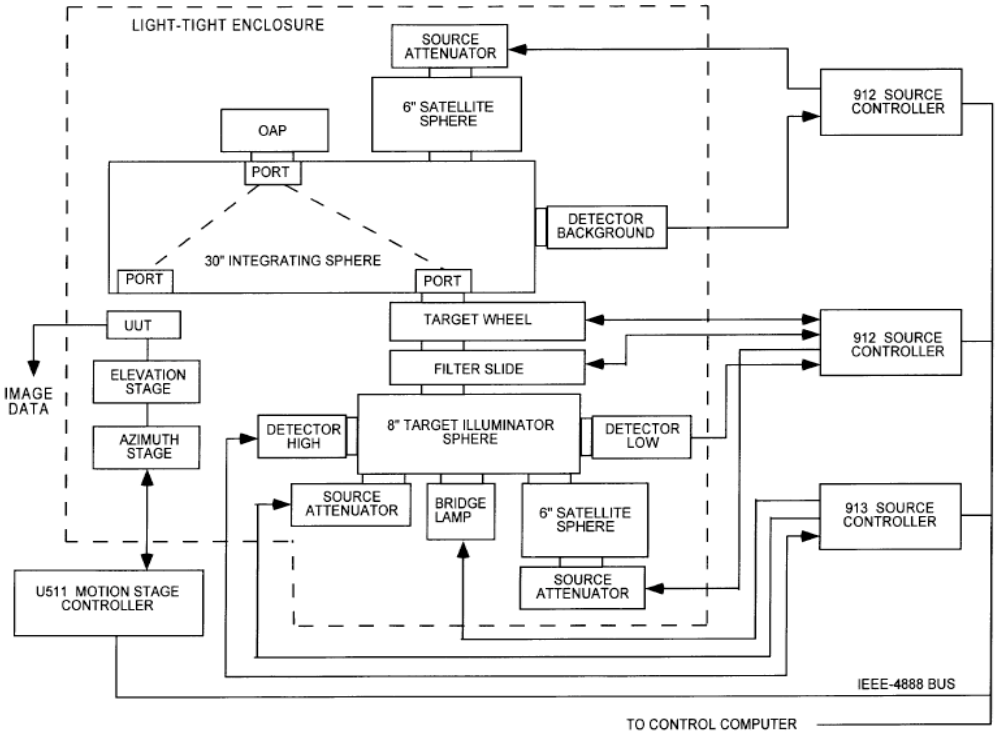

Figure 2 – Functional Block Diagram

The system is mounted on an optical bench. A light tight enclosure provides a completely dark test environment. The system is centered around the 30" integrating sphere which is arranged such that the target plane is focused via the OAP, (off axis paraboloid mirror), to provide collimated target image output to the UUT port. Background illumination is provided from a 6" satellite sphere illuminated buy a source/attenuator controlled by a 912 source controller based upon measurement data provided by the background detector.

The target is positioned at the input port in front of the filter slide and both are illuminated by the target illuminator. The target illuminator consists of an 8" target illuminator sphere, 6" satellite sphere, two source/attenuators a bridging lamp and two detector preamplifiers. Illumination level measurement feedback information for the high range of luminance is provided by the detector high to the 913 source controller which, in turn, controls the opening/closing of the source attenuator vanes to achieve the commanded luminance. In order to achieve the full range of luminance, a bridging lamp, is used to supplement the output of the source/attenuator at the highest luminance levels, (above5,000 Lux). Illumination level measurement feedback information for the low range of luminance is provided by the detector low to the 912 source controller which, in turn, controls the opening/closing of the source attenuator vanes to achieve the commanded luminance. This 912 controller also provides control for positioning the selected target in the operating position and provides control for filter selection and positioning.

The UUT is mounted on an azimuth and elevation motion stage, the positions of which are controlled by the U511 motion stage controller. Source controllers and motion controller are connected to the control computer via an IEEE-488 bus. The control computer, running SBIR IRWindows software, sets the required luminance levels via the source controllers and positions the Motion stages for the UUT. The computer acquires image data from the UUT and processes it with the selected test routine in order to determine camera performance.

The collimator sphere and illuminators are shown in Figures 3 and 4.

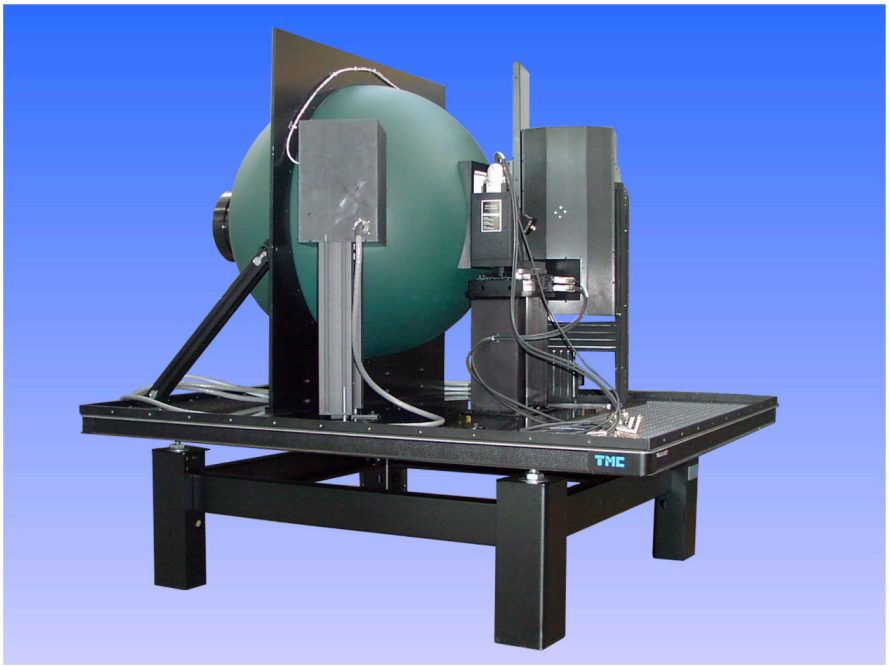

Figure 3 – View of Projector System with Cover Removed

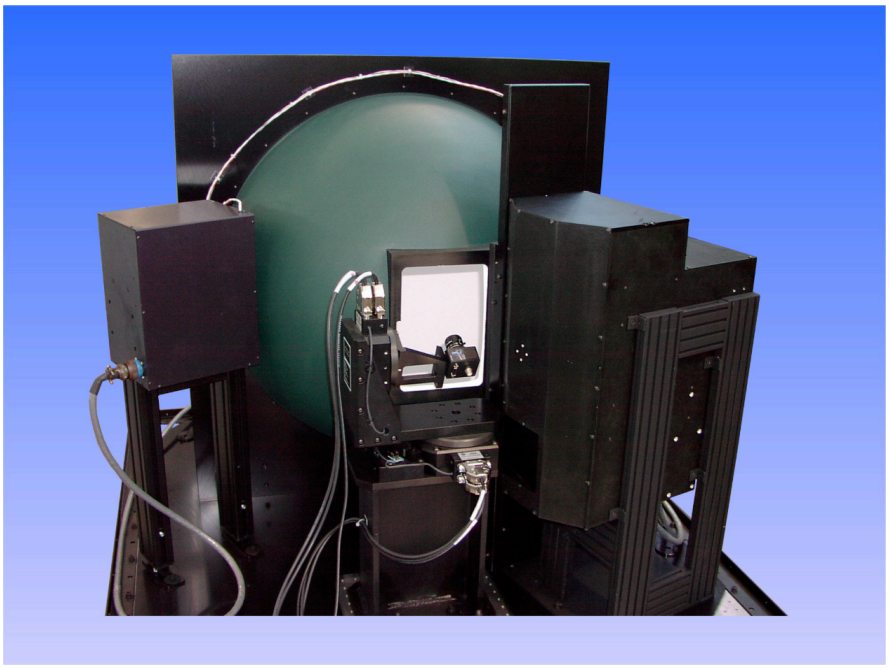

Figure 4– View of UUT Interface and Motion Stages

The completed projector system has been delivered, and is in the early stages of operation in the field. So far, no significant issues have arisen and performance data is being accumulated.

SUMMARY

SBIR has developed this new concept collimator system to fill the need for automated evaluation of day/night cameras for a variety of applications. The system includes a number of novel design solutions, including a collimator built within a large background integrating sphere, an extremely wide output luminance dynamic range, and support for wide FOV UUTs.

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