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Imaging Criteria and Test Methods
for Qualification of Iris Cameras

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Acknowledgments

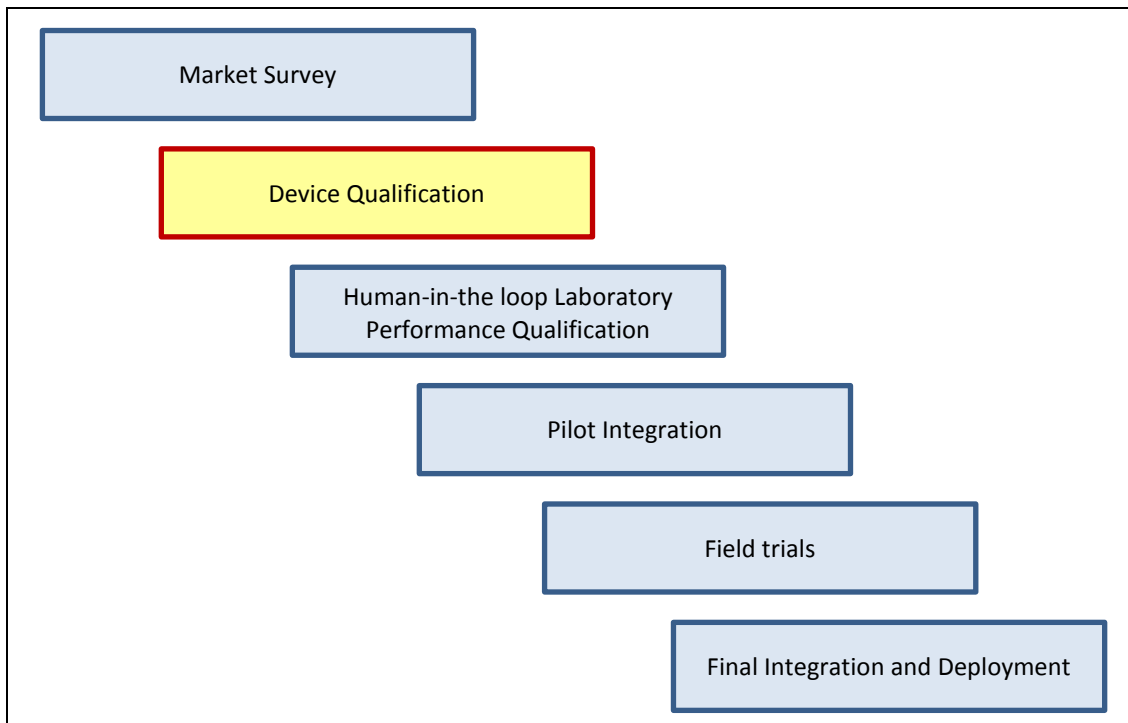
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97

98 **1 Introduction**

99 This document defines an iris camera evaluation and qualification test funded and developed by the
100 Department of Homeland Security, Science and Technology Directorate (DHS S&T), Homeland
101 Security Advanced Research Projects Agency (HSARPA), and NIST. These efforts are intended to aid
102 in the consideration of iris biometrics for applications ranging from building access control to
103 expedited and secure processing of foreign nationals at, air, sea, and land ports of entry. Device
104 qualification is necessary for mitigation of risks associated with capture of poor iris images. Its role is
105 prior to technology deployment, and it may be used in cost benefit analyses, and facilitate an
106 efficient procurement process.

107 The document is part of a larger tiered process that attempts to separate the lower level device
108 performance characteristics from how these potential capabilities work in real applications where
109 human behavior may significantly influence image quality as it relates to iris biometrics (Figure 1). This
110 document presents a series of optical tests which are specifically designed to evaluate the device-
111 level image quality aspects of iris biometric capture device. It does not attempt to address the more
112 complicated yet important human interactions between a device, an attached system, the human
113 subject, the device operator, and the operational environment. These aspects are amenable to test
114 under, for example, the ISO/IEC 19795 Biometric Performance Testing and Reporting standard. This
115 first tier of the test, the Iris Device Qualification Test (IDQT) provides content for down selection
116 decisions of devices prior to human-in-the-loop testing for US Government applications.



117 **Figure 1** The procurement process for iris biometric technology for an arbitrary application follows a serial
118 tier from an initial market survey of possible device solutions to a full deployment and integration into
119 existing infrastructure. This document focuses on the test and procedures needed to fulfill device
120 qualification.

121 The motivation to separate the device qualification as a prerequisite for further testing is both
122 technical and economical. Human performance testing in a laboratory or a field location is often
123 more expensive and time consuming compared to device level testing, and is not repeatable due to
124 population variance effects. Creating a device qualification pre-requisite prevents expending
125 resources on testing devices whose peak imaging performance falls short of application
126 requirements. On the technical motivation, the specific products of the device-level evaluation give
127 insight into the strengths and weaknesses of a given device removed from human elements, allowing
128 comparative studies of devices to be used in later stage testing and evaluations. It also allows for a
129 confirmation of manufacturer's performance claims relative to application-specific requirements
130 and/or the requirements and recommendations stated in ISO standards¹.

131 The following sections present the IDQT plan. Section 2 outlines the scope of the test, and the
132 specific metrics used in the test. Section 3 reviews the testing equipment required to conduct the
133 test, and the rationale behind the design of the test equipment. Section 4 reviews the specific
134 procedures involved in each test in collecting, and processing the image and diagnostic data, which
135 are used to formulate the suite of quality metrics. Finally, Section 5 outlines the criteria for
136 qualification, along with their technical justification.

137 **2 Test Overview and Scope**

138 The information gathered from the IDQT is, by design, intended to measure “peak” imaging
139 capability using metrics relevant to the signals contained in near-infrared images of the human iris
140 used by recognition algorithms. The test is repeatable and should therefore be able to discern
141 whether or not a device, removed from all human factors, is suitable as an iris capture device.

142 The IDQT follows a conventional image quality assessment procedure, whereby a series of calibrated
143 optical patterns are presented to the imaging device undergoing evaluation followed by the
144 computation of relevant metrics from the captured images. With the output metrics from this test in
145 hand, comparison can be made to qualification criteria to make a judgment on the suitability of a
146 given device for further consideration. The test has been designed to accommodate measurements
147 which exceed the current guidelines with the rationale that the information content requirements of
148 future matching algorithms may increase over time. However, as expanded upon in Section 5, the
149 exact qualification criteria used in a given project would likely depend on the application.

150 Where possible this document specifies the use of image quality assessment hardware and software
151 that is standardized, published and widely available. However, in many cases, existing techniques
152 were found to interfere with the operational image capture processes and this necessitated the
153 development of equipment and techniques dedicated to iris device qualification. Other non-imaging

¹ These are:

- The published iris interchange standard ISO/IEC 19794-6:2011 Information technology -- Biometric data interchange formats -- Part 6: Iris image data which revises and replaces the 2005 iris standard.
- The draft iris image quality standard ISO/IEC 29794-6 Information technology -- Biometric sample quality -- Part 6: Iris image which defines acceptable properties of iris images.

154 tests are included, such as the characterization of the on-board illumination in the context of eye
155 safety standards, and the basic physical measurements of dimension and weight. The optical
156 properties of the eye and face region are incorporated into the test targets to ensure the evaluation
157 devices capture images of test targets as they would of real irises.

158 The collection and analysis procedure is designed to accommodate different capture modes which
159 may influence how a particular device is evaluated. The intent here is to support qualification
160 devices running in different capture modes. Capture-mode diversity is distinct from how a device can
161 be used in different applications, and although this test covers different capture modes the
162 qualification criteria are application dependent. For example, one device could be used for collection
163 of images for national scale deduplication, and for outdoor access control. The qualification criteria
164 could be different for the two applications.

165 **2.1 Device Capture Mode Classifications**

166 Specific considerations of the iris image capture process have been made in the IDQT collection and
167 analysis procedure to accommodate a variety of possible operating modes. While conventional
168 enrollment devices produce single images of the left and right eyes, a new generation of iris capture
169 devices explicitly tradeoff capture speed for accuracy to facilitate applications such as high-
170 throughput access control. In such cases, the number and quality of iris images output by a device
171 for one presentation of a subject may vary and it is not necessary that all output images are of a high
172 quality. Such “opportunistic” modes of operation continuously feed images through an operational
173 iris recognition algorithm essentially using a (fast) iris matching process as a quality filter. Aspects of
174 this mode of operation have been incorporated into the test procedure in an effort to make the IDQT
175 a minimally biased evaluation applicable to a wide variety of applications.

176 A definition of a capture event is used which encompasses a range of operational modes. The start
177 of a capture event is defined according to manufacturer’s documentation, typically initiated by a
178 command through a supplied demonstration application, or from the appearance of a face in a
179 specified capture volume. The end of a capture is defined according to the manufacturer’s
180 documentation, marked by a message received from the device by the control computer for
181 example. If the end point is not well defined by continuous capture devices for example, a period of
182 ten seconds is allowed for the capture process to take place for each capture. This definition is
183 applied to the following classes of capture modes used in the test outlined below.

184 **Single Image Mode**

185 The single image mode of operation results in the device providing one iris image for each
186 presentation. Each image taken during the collection process in single image evaluations is used in
187 the evaluation analysis.

188 **Opportunistic Stream Mode**

189 For each presentation, multiple images are output from devices in opportunistic mode. Out of the
190 series, the image with the highest performance metric is used in the evaluation analysis.

191 **2.2 Liveness Detection**

192 Some devices may have liveness detection features which may prevent the release of an image, or
193 compromise the capture process. In order to test such devices, the manufacture shall disable these
194 capabilities.

195 **2.3 Acceptable Image Formats**

196 The IDQT accommodates a wide variety of output image types, not restricted to the widely used
197 640x480 eight-bit greyscale format compatible with commercial matching algorithms. This test can
198 accommodate any format which can be translated into the numerical pixel values of the images and
199 their correct orientation relative to the focal plane. Image formats include ISO/IEC 19794-6, PNG,
200 JPEG 2000, TIFF, and bitmap or any format for which access to the relevant data elements is
201 supported and defined. If problems are encountered reading the supplied image format, or if the
202 format contains multiple channels when one is expected, the device manufacturer shall afford a
203 remedy after appropriate notification. The format of the output images shall be included in the
204 report. Although some basic information regarding the format of the images output from iris capture
205 devices, this test does not replace a formal standards-conformance test to ISO/IEC 19794-6.

206 It should be noted that although the IDQT does not test explicitly evaluate device output format, this
207 fact does not imply that DHS or other Federal applications will not have output format requirements
208 at later-stages in the down selection process.

209 **2.4 Interoperability**

210 Currently there are many available commercial matching algorithms and iris capture devices. This
211 availability has increased substantially in recent years. Interoperability of the images taken from
212 different device manufactures is important in federated multi-party applications. Interoperability
213 facilitates competition and minimizes long term risk associated with depending on one proprietary,
214 non-interoperable commercial solution.

215 While device-level testing and qualification is intended and expected to improve interoperability,
216 there is as yet limited understanding of root-causes of cross-device recognition accuracy
217 degradation. Particularly because human-interaction effects may play a role, tests such as those
218 defined in ISO/IEC 19795-4 Performance Interoperability Testing are most suited to quantifying cross-
219 device recognition accuracy.

220 The metrics collected in this document's qualification processes will support analysis of cross-device
221 interoperability effects. In particular, by correlating results with empirical recognition trials, it might
222 reveal device level root-causes of non-interoperable behavior. This motivates the repeatable, purely
223 optical test of imaging capability given in this document.

224 Although this test may give the US Government insight into the possible root cause of potential
225 interoperability shortfalls, there are no explicit reporting mechanisms related to interoperability
226 resulting from the IDQT.

227 **2.5 Levels of qualification**

228 **Enrollment versus Verification Criteria**

229 Typically, application requirements dictate that the database of enrollment images is of a higher
230 quality relative to the image used for verification. It is conceivable that this device qualification may
231 have separate criteria for enrollment and verification applications. However, the definition of an
232 “enrollment quality” image is application specific, in particular on the false match and non-match
233 performance levels the application requires. For example, an application involving just 1-1
234 verification may require less quality compared to a program which is attempting to de-duplicate a
235 nation's individuals. Also, the determination of enrollment quality lies heavily on human
236 presentational issues, such as occlusion, eye gaze, and pupil dilation state which are not possible to
237 control on a device level test. Therefore, although the output metrics from this test support
238 qualification of a device (for enrollment, say), they do not ensure that all images will be suitable for
239 enrollment. The qualification criteria from the IDQT may provide a basis for in a down selection
240 process of an enrollment device versus a verification device, but because these criteria are
241 application dependent the IDQT does not fix a definition for an enrollment quality image versus a
242 verification quality image.

243 **2.6 In-Scope Measurements**

244 The following subsections review the specific device level elements that are in scope for this test.

245 **Spatial Frequency Response**

246 Spatial Frequency Response (SFR), analogous to the Modulation Transfer Function (MTF), is a metric
247 used to quantify the amplitude attenuation and phase change of imaged sine wave patterns of
248 varying frequency through an optical system. Quantitatively, at a given spatial frequency the SFR is
249 the modulation of a sine wave at that frequency seen in the image divided by the modulation in the
250 original object plane. The MTF can also be expressed as the complex amplitude of the Fourier
251 transform of the Point Spread Function (PSF). The Contrast Transfer Function (CTF) is a similar metric
252 to the MTF of an optical system, but is calculated on the basis of a square wave pattern rather than a
253 sine wave pattern. The SFR is relevant to iris biometrics as feature extraction algorithms use a
254 limited range of spatial frequencies from the iris pattern seen in near infrared (NIR) images. Each
255 algorithm may use a specific set of spatial frequencies, Removed from the spatial frequency
256 response of iris matching algorithms, criteria for the SFR metric can be arrived at based on ISO
257 standard recommendations of the spatial sampling rate, Nyquist sampling theory, and assumptions
258 regarding the point spread function as outlined in appendix xxx.

259 **Pixel Scale**

260 Pixel scale describes the number of pixels occupied by a physical distance in the object plane, in this
261 case in the physical plane of the iris. The pixel scale is important as it relates to the spatial sampling
262 rate which determines whether the PSF is adequately sampled. Irises typically range between 10.2

263 and 13.0 mm with an average of about 11.8 mm². ISO recommendations based on results from the
264 IREX III study³ suggest that images which should have a pixel scale with at least 160 pixels across the
265 iris diameter giving a pixel scale between 15.7 and 12.3 pixels/mm. A refined guidance for pixel scale
266 is outlined in section 5.

267 **Iris Albedo Texture SNR**

268 The information used in iris biometrics is comprised by subtle light and dark pattern variations
269 intrinsic to the iris, outlined further in Section 3. Physically, the signal source is the NIR albedo
270 variations across the iris that has amplitudes of less than a few percent on top of a fairly dark albedo
271 with median of around 15%. The metric developed in section 4 specifically created for this test
272 measures the effective response of the filtering effects of a typical iris encoding and matching
273 process using iris-like texture in an attempt to provide a near “bottom line” measure of how well an
274 optical system records iris-like features.

275 **Field Distortion**

276 The field distortion can be defined as the position dependence of the pixel scale in the image plane.
277 There are no quantified ISO recommendations for this metric. It should be noted that some forms of
278 field distortion may be mitigated through the iris segmentation and pseudo-polar transform
279 operation carried out in common matching algorithm paradigms. The metric is based on an
280 integrated area of distortion relative to three nominal length scales used in the three levels of
281 qualification criteria outlined in section 5.

282 **Greyscale Gain Linearity**

283 The greyscale gain linearity refers to the relationship between the number of NIR photons recorded
284 in a pixel and the expressed digital value of the pixel. This relationship may be non-linear depending
285 on the camera processing and/or sensor characteristics. Although there are no ISO standard
286 recommendations regarding gain variations, non-linearity may be the source of interoperability
287 issues, and segmentation failures for some algorithms expecting a linear signal, for example.

288 This quality aspect is measured using a supplied target which has regions of known NIR albedo
289 covering the range of interest for iris biometrics.

290 **Object Plane Albedo Resolution**

291 Iris information is conveyed through spatial variation in greyscale. Insufficient sampling of the albedo
292 distribution will lead to a reduced number of grey levels in the captured image. The object plane
293 albedo resolution refers to the smallest change in albedo that can be detected by the device. The
294 metric is based on the number of grey levels spanning the 0.8 to 0.25% range of NIR albedo targets.
295 Because this magnitude of the albedo resolution depends on the scale of the feature size, the metric
296 uses the three scales used which define the three levels of qualification from section 5
297 (0.75mm,0.375mm, 0.25mm) to define area sizes used in the metric creation.

² Andre Caroline, Effect of Corneal Diameter on Soft Lens Fitting, *Contact Lens Spectrum*, Vol. 17, No. 4, 2002.

³ P. Grother, G.W. Quinn, J. Matey, M. Ngan, W. Salamon, G. Fiumara, C. Watson, Iris Exchange III, Performance of Iris Identification Algorithms, NIST Interagency Report 7836, April 9, 2012. <http://iris.nist.gov/irex>

298 **Ambient Light Mitigation, supplied illumination corneal reflection map**

299 The cornea reflects about 2-3% of the incident ambient light. If this reflection overlaps with the iris
300 from the camera's viewing angle, the reflected scene may be superposed with the iris information.
301 This test evaluates a given device's ability to mitigate ambient light noise, and maps out the
302 reflection scene from a device's supplied illumination.

303 **Exposure Time Estimation**

304 A test is included which estimates the device's effective exposure time using a series of spatially
305 separated lights which are turning on and off with a known synchronization. Exposure time has some
306 relevance to iris biometrics as shorter exposure times translate into a higher acceptable error in
307 tracking subject motion. This metric should be taken with the caveat that some systems may have
308 sophisticated closed or open loop tracking systems which result in low tracking errors even with high
309 subject velocity and/or acceleration. This test does not explicitly evaluate device performance as a
310 function of subject motion. However, such a test could be accomplished through placing the test
311 targets on motion platforms which cover a realistic range of subject and/or operator motion.

312 **Supplied Illumination Spectrum**

313 Depending on the eye color, the human iris exhibits different patterns as a function of wavelength.
314 Blue eyes do not have a front facing pigment layer, so the characteristic pattern is similar from the
315 visible to NIR wavelengths with features becoming lower in contrast with higher viewing wavelength.
316 Brown eyes however have a pigment layer which is essentially opaque to visible wavelengths, but
317 optically thin to NIR wavelengths. In the NIR, the pattern underneath this visibly opaque layer
318 contains higher contrast and higher albedo features. The appearance of the iris pattern changes with
319 wavelength, particularly brown eyes are dark and relatively featureless in visible wavelengths so iris
320 imaging almost always uses NIR wavelengths between 700nm and 900nm. Additionally, the limbus
321 boundary has lower contrast at 900nm and this can affect segmentation.

322 The output metric reports a low spectral resolution (20nm) measurement of the spectral irradiance
323 between 700 and 900nm integrated over sufficient number of capture events. This test assumes that
324 the main source of iris illumination is from the device itself.

325 The draft ISO/IEC 29794-6 standard has three requirements on spectral composition in the range
326 [680,920]nm. These are:

- 327 1) That 90% of power on [680,920] resides in [700,900];
328 2) At least 35% of power in [700,900] resides in [700,800]nm and
329 3) At least 35% of power in [700,900] resides in [800,900]nm.

330 **Editor's NOTE:** This document does not currently formalize a requirement on spectral composition
331 for iris capture devices because no good study exists. Comments are sought on whether and how to
332 formulate requirements in this area.

333 **Eye Safety**

334 This test includes the spectral characterization of the supplied illumination, as well as irradiance
335 measurements to compare with the ACGIH eye safety threshold limit values⁴.

336 **Capture Volume**

337 The capture volume is the physical space which an iris capture device can produce an image which
338 satisfies a qualification criteria. In the case of iris biometrics, some devices will not instigate or
339 release the results from an image capture sequence without a subject present in a specified capture
340 volume. The capture volume will be measured relative to the stated volume from the
341 manufacturer's specification.

342 **2.7 Out of Scope**

343 Although some of the information gathered in this test can reveal important performance details of a
344 given device, the test laboratory shall not report backwards engineering on specific device
345 parameters. Namely device characteristics such as the aperture size and F number, sensor quantum
346 efficiency, sensor noise characteristics, image stabilization techniques, or post processing methods
347 used are not explicitly evaluated.

348 The test does not explore the influence of operational environments including temperature
349 variations beyond nominal room temperature, humidity variations, and long term effects of outdoor
350 exposure to dusty and corrosive conditions.

351 The IDQT does not specify tests for ruggedization, durability, and vulnerability to malicious
352 exploitation.

353 **3 Test Design and Equipment**

354 The IDQT test procedure and equipment are designed with the goal of accurately measuring the peak
355 imaging capabilities in the context of iris biometrics in a way which minimizes biases that would
356 misrepresent the performance of one device over another. An example of a possible source of bias is
357 that some devices use the optical features of the face and eye in the capture process to automate
358 tracking and focus and a test using optical targets, which does not accurately include these important
359 features at a level of realism required by the iris camera, may interfere with the capture process for
360 these devices. Also, the iris texture relevant for iris biometrics is confined to a fairly narrow range of
361 NIR albedo variations as discussed previously. Most off-the-shelf imaging targets consist of high
362 albedo contrast patterns which do not represent real iris features. Besides the possible capture bias
363 mentioned above, diagnostic measurements using COTS targets may overestimate the performance
364 in recording information available from the iris. In short, without targets that accurately represent
365 real face and iris features, the test may misrepresent performance of certain devices relative to
366 others.

⁴ ICNIRP Statement on Light-Emitting Diodes, Implications for Hazard Assessment
<http://www.icnirp.de/documents/led.pdf>

367 The following section reviews the details test equipment developed by DHS S&T/HSARPA specifically
368 for the IDQT and the rationale behind the test design.

369 3.1 Human Face Optical Target Mount

370 A three dimensional representation of a human face is required for this test for two reasons. First, a
371 number of iris capture devices use the features of the face to locate and track the eyes for iris
372 imaging. Without a realistic presentation of at least generalized face features, some devices will fail
373 to perform image capture. Secondly, light scatters from the nose and eye socket, which
374 subsequently reflects from the corneal surface and back into the camera aperture. These nose and
375 eye socket reflections may constitute a noise source, and therefore a model representing the 3D
376 profiles of the face features, along with at least the general scattering features of the skin is required
377 to test these aspects of iris biometrics.

378 These face features need to be reproducible and well defined to enable the repeatability of the test.
379 After an extensive exploration of the near infrared scattering properties of various readily available
380 materials, the decision was made to use 3D printing technologies to create the face and optical
381 target mounts. These models are shown in Figures 2 and 3.

382 The model of the face was chosen using software and a face dataset from a commercial source. The
383 face used in the IDQT model was generated from an average face representation from a large and
384 diverse population of faces. This 3D model was scaled preserving aspect ratio such that the
385 interpupillary distance matched the a nominal mean of 63 mm⁵



Figure 2 A 3D representation of an “average” human face with a mounting solution for model eyes which have specialized optical targets (Figure 3). The face model has a ¼-20 thread on the bottom to facilitate mounting to optical bench hardware to accurately control stand-off distance and presentation angle to evaluation devices

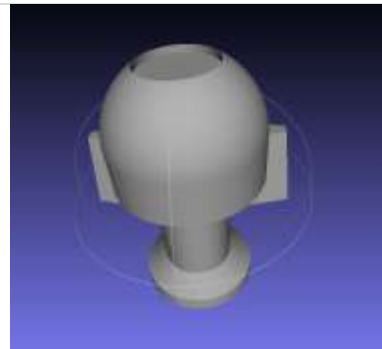


Figure 3 An design for the eye target blank which fits inside the face mount shown in Figure 2. The piezography printed pattern and cornea simulation solutions fits inside the front facing indentation in the design. The reflective properties of the 3D printed model is similar to that of the human sclera as seen in near-infrared wavelengths.

⁵ Dodgson, N., “Variation and Extrema of Human Interpupillary Distance” Proc. SPIE Vol. 5291, Stereoscopic Displays and Virtual Reality Systems XI, A. J. Woods, J. O. Merritt, S. A. Benton and M. T. Bolas (eds.), 19–22 January 2004, San Jose, California, USA, ISSN 0277–786X

386 The face is augmented with sets of artificial eyebrows and lips with a different contrast relative to
387 the skin regions to provide realistic signal for face detection algorithms.

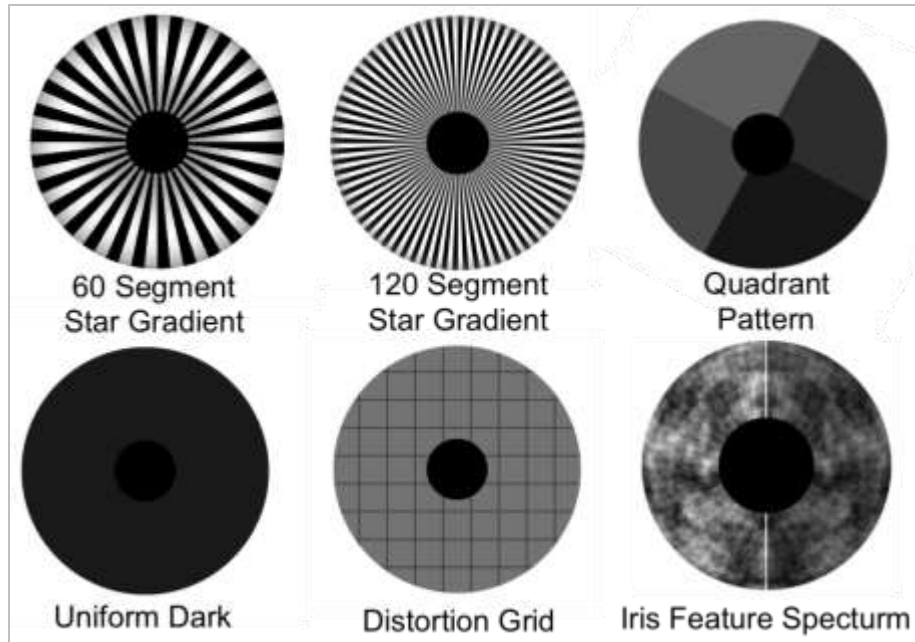
388 **3.2 Optical Target Design and manufacture**

389 The optical targets used are mounted in the eyeball-like base model of Figure 3. This was
390 manufactured from a digital model using 3D printing technology. The front of the base has a 12 mm
391 diameter circular indentation to accommodate the various optical target patterns which are chosen
392 to be the size of the typical human iris². The model of the optical eye target has two keyed tabs
393 which fit into grooves in the side of the holding cylinders on the back side of the face mount. This
394 can accommodate 90 degree axial rotations of the eye target to control against possible systematic
395 influences of the target manufacture. One of the two keys is colored and the groove positions are
396 numbered 1-4 to consistently position the targets, and keep track of the rotation orientations used.

397 **3.3 Review of Specific Diagnostic Image Target Patterns**

398 The patterns are printed on paper using piezography carbon-based ink using a high resolution inkjet
399 printer calibrated to produce controlled NIR albedo values as a function of spatial frequency. The
400 target patterns used in the IDQT, shown in Figure 4, have been designed to incorporate and
401 represent the features used in iris biometrics, namely the NIR albedo contrasts of the iris pattern,
402 and the pupil and limbus borders. Explanations for each target used in the test follows in subsections
403 below.

404 A number of target patterns used for image analysis have been created to fit in a circular area with a
405 diameter of 12.0mm, or inside the nominal area of a typical iris. These patterns fit inside the eye
406 model described in section 3.2 and have been designed to work with analysis algorithms designed to
407 extract image quality information relevant to iris biometrics. Before use the albedo of the printed
408 patterns are validated using calibrated albedo targets and a large format NIR camera system which
409 produces images with a modulation of greater than 0.95 at a frequency of 20 lp/mm and below, or
410 significantly higher frequencies than conventionally used in iris biometrics.



411

412 **Figure 4** The six target patterns used in the IDQT are shown above. Each target has a diameter of 12.0mm
 413 and a pupil diameter of 4 mm.

414 **3.3.1 Quadrant Pattern**

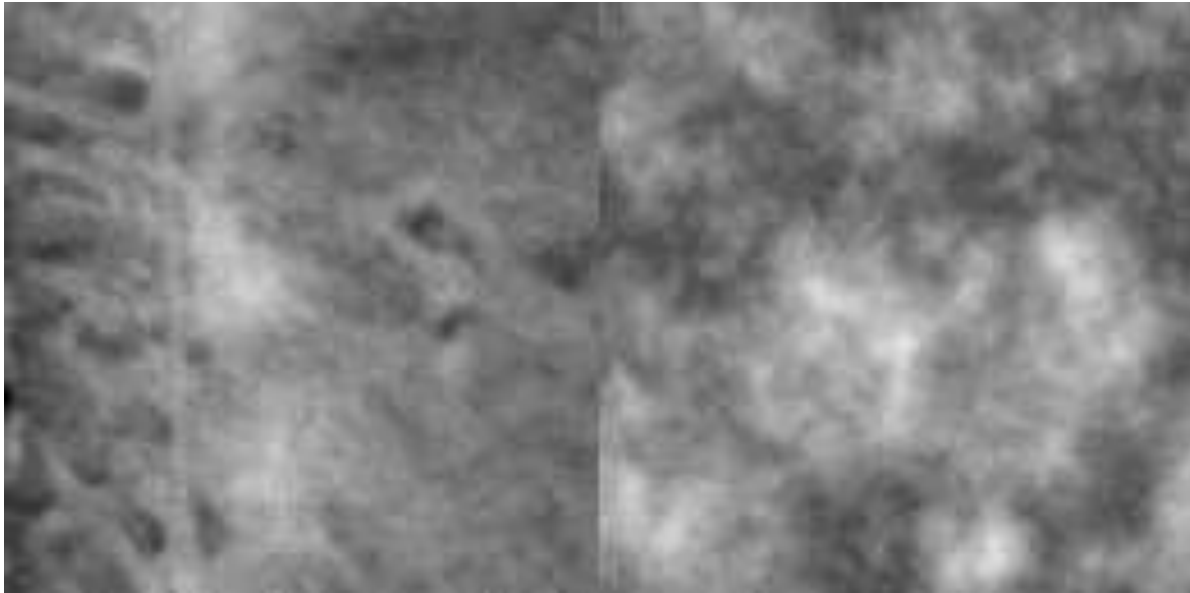
415 The quadrant pattern consists of four even-area 90° slice sections each assigned a different
 416 calibrated NIR albedo value. The values used in the four regions (0.08, 0.14, 0.20, 0.26) are chosen to
 417 span the range of albedo found in the iris. The edges have a rise with a half-width at half-maximum
 418 on the order of 10 microns to facilitate slanted-edge MTF measurements using the line spread
 419 function in the range at frequencies lower than ~10lp/mm. The four areas are large enough to
 420 produce independent noise measurements as a function of spatial scale spanning scales from
 421 0.2mm-2mm, with the target paper texture limiting noise measurements at higher spatial
 422 frequencies. The resulting albedo variations are characterized and accounted for in the statement of
 423 the metric for linearity and slanted edge MTF resulting from the test.

424 **3.3.2 Iris-Like Feature Spectrum**

425 This target is intended to represent the near infrared albedo features of the iris. The goal of this
 426 target is to produce a pattern with an albedo amplitude distribution which is in the range of real
 427 irises. To guide the pattern design, characterization of the near-IR iris pattern was conducted using a
 428 portion of the University of Bath iris image database⁶, and using nominal values of the image scale
 429 using a nominal value of iris diameter of 11.8 mm. Iris texture not obscured by eyelids, lashes, or
 430 bright specular reflection was Fourier analyzed in ~2.5x2.5 mm square bins as seen in Figure 5a.
 431 Although individual bins may exhibit departures from the average, a fit to the radially averaged
 432 power spectra (Figure 5b) of the bins fit the profile of a random Gaussian field with an amplitude

⁶ University of Bath Iris Database (<http://www.smartsensors.co.uk/information/bath-iris-image-database/>)

433 distribution following a power law exponent value of $-11/3$ with feature size within a range between
 434 0.07mm to 1 mm, as shown in Figure 6.



Example NIR Iris Texture

Random Gaussian Field with PLC=-11/3

435
436

437 Figure 5 An example of the 2D NIR iris texture shown in comparison with a random Gaussian field with a
 438 power law coefficient (PLC) of $-11/3$. Across many iris images sampled at frequencies with high MTF (greater
 439 than $\sim 80\%$) the value of $-11/3$ was found to be the best general fit to the measured iris texture power
 440 spectra.

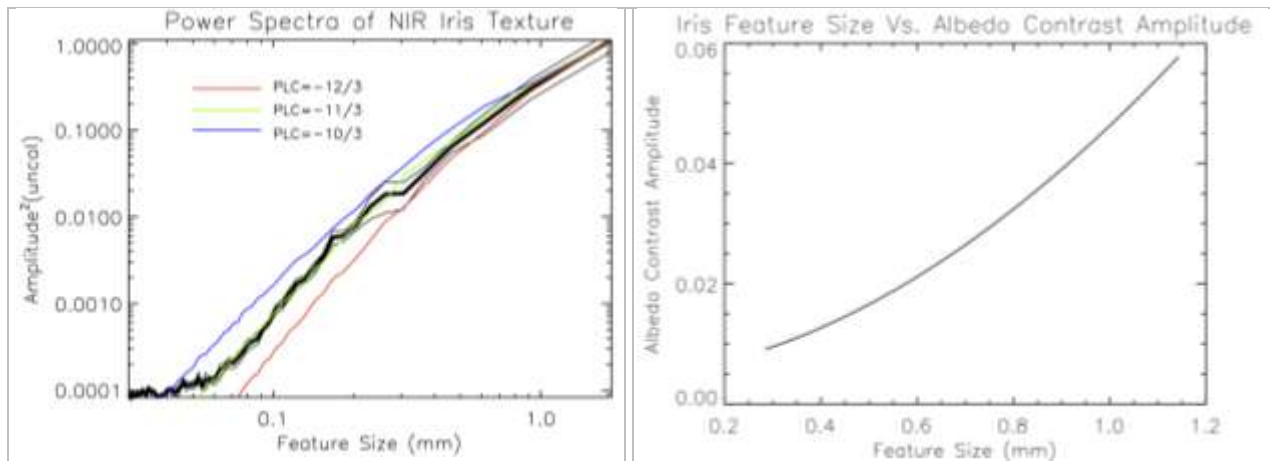


Figure 6 An example power spectra of the 2D iris texture information as recorded by near infrared imaging shows (black line) that the iris texture follows a power law distribution with a coefficient (PLC) equal to $-11/3$. The different color lines shows different PLC values for comparison, with the blue line showing a slightly more even distribution with PLC= $-10/3$, and the red line a steeper distribution with PLC= $-12/3$. (need to show the plot representative of

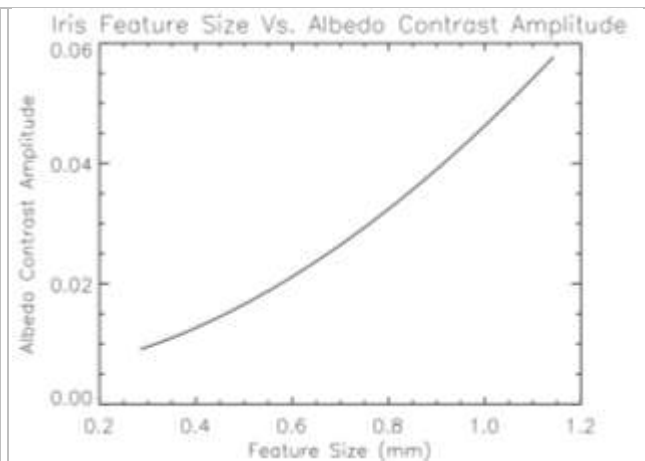


Figure 7 The profile of the albedo contrast as a function of feature size is shown from the resulting power $r^{-11/3}$ relationship established in Figure5b and matching the absolute. (consider plotting 1 sigma or some nominal value above the average... the low contrast features will be masked out via fragile bit filters)

441 **3.3.3 Gradient Contrast Star Patterns (60 and 120 segments)**

442 These targets are designed for direct measurement of the CTF using contrast targets with albedo
443 characteristics representative of those measured for the human iris. The 60 segment gradient
444 contrast star pattern covers frequencies ranging from 0.8 lp/mm to 3.5 lp/mm. The 120 segment
445 pattern covers a higher range between 6.5 lp/mm and 1.6 lp/mm. There is a slight overlap in
446 coverage between the two targets to confirm results with separate physical targets for the level II
447 and level III criterion. Following the $-11/3$ power law relationship of the power spectrum of iris
448 texture, the albedo contrast amplitude representative of typical iris features as a function of feature
449 size is shown in Figure 7. The dark and bright regions are set to have a difference of 0.03, or the
450 typical value of iris features which are around 0.7mm in size. Although this strategy may overstate
451 performance on typical iris texture at smaller sizes, setting uniform albedo values with radius for a
452 given angle simplifies both the CTF extraction algorithm, and creating the target. Also, although the
453 average albedo contrast of iris texture at high spatial frequencies may be lower than the 0.03 value
454 of the test target, the iris features observed at scales at the lower range of our consideration ~ 0.1 mm
455 are at or above this contrast.

456 **3.3.4 Uniform Dark**

457 A uniform, dark background is ideal for mapping out the distribution of reflected light from the
458 cornea overlapping with the iris area. The uniform dark target consists of a uniform albedo of 0.08
459 across the whole of the iris region. The texture of the paper results in a departure from uniformity at
460 small spatial scales. The residual RMS albedo error from the printed paper target under uniform
461 illumination is taken into consideration in the formation of metrics.

462 **3.3.5 Distortion Square Grid**

463 The square grid target consists of lines of width 0.1mm spaced 1.3mm apart. The line pattern is
464 printed with an albedo of 0.05, with the background at 0.16. This pattern is used to estimate the
465 field distortion of image capture devices. The field distortion is expressed as absolute spatial
466 displacement error relative to a linear model presented normal to the optical axis. The output metric
467 is expressed both in object plane Cartesian and the conventional "pseudo-polar" coordinates used in
468 iris biometrics.

469 **3.3.6 Exposure Time Target**

470 This target is comprised of 14 optical fibers implanted in the iris area evenly spaced in two radial
471 layers. The fiber diameters are 0.5mm, and are coupled to the light output of 14 separately
472 controlled LEDs which are optically isolated from each other with rise times on the order of 5 ns. The
473 brightness of the LEDs are small compared to the typical return from an iris capture device, and can
474 be controlled if the brightness interferes with the capture process for devices which use the corneal
475 reflection. The 14 lights sequentially turn on and off, configured to be at 5ms intervals. In a given
476 image of this target, the number of fibers illuminated is an indicator of the exposure time up to
477 about 60ms.

478 **3.4 Representation of Corneal Reflection**

479 Two different methods are used to represent the reflection characteristics of the cornea. The
480 corneal reflection from device-supplied illumination can be used as feedback for tracking and focus
481 control so it is important to replicate these physical characteristics in the target to avoid bias. In
482 addition, the ambient light reflection of the corneal surface may be a significant source of noise in iris
483 images, and so this needs to be incorporated into the test as well. One set of IDQT optical targets
484 use a smoothly curved surface of UV curing glue placed in the pupil center with a chosen index of
485 refraction and radius of curvature to simulate a corneal reflection. A second set of IDQT targets use
486 magnesium fluoride (MgF₂) coated spherical lenses with a radius of curvature of 7.75 mm, which is
487 similar to that of the human cornea, tear reflection surface. Versions of each optical target are made
488 using both techniques and incorporated into the data collection procedure.

489 All patterns are used with the UV cured glue corneas as these give an unobstructed view of the target
490 pattern. The MgF₂ lens targets are only used with the uniform, dark and iris texture patterns for
491 suitability assessment for different ambient light environments.

492 Neither target design accurately represents the “red-eye” return aspect of the human eye observed
493 when the illumination sources are near the entrance aperture of the imaging device. Thus, the target
494 design cannot accommodate devices which may use the red-eye return aspect of human eyes in the
495 capture process.

496 **3.5 Vibration Environment**

497 Mechanical vibration is controlled through a floating optical bench with an active vibration
498 dampening system, which provides a vibration environment less than VC-C velocity based
499 environmental vibration criterion which is below the operational theater ISO standard.⁷ Suitability
500 for different vibration environments are not covered in the IDQT. Considering the wide variety of
501 vibration environments possible including a vibration environment suitability test would not be
502 practical. Potential issues regarding vibration would presumably be discovered at later stage field
503 testing.

504 **3.6 Eye safety and Device illumination Characterization**

505 The IDQT measures the evaluation device irradiance with a calibrated irradiance meter at the range
506 of standoff distance for recommended use from the vendor, with measurements taken between this
507 distance and the closest standoff distance a subject could conceivably come to the device
508 illuminator. For addition illumination characterization, one eye target has a 1 KHz response photo-
509 diode incorporated into the pupil region, as well as an eye target with a fiber collimator which feeds
510 into a NIR spectrometer. These devices allow for a both a wavelength and time dependent pulse
511 characterization which will be included in IDQT evaluation reports. The pulse characterization is
512 meant to provide additional input to augment exposure time estimates, to encompass the possibility
513 that some capture devices may use pulsed illumination as the effective method to “freeze” motion

⁷ Gordon, C.G., *Generic Vibration Criteria for Vibration-Sensitive Equipment*, SPIE,3786,22, 1999

514 rather than exposure time. In addition, eye safety threshold limit values as outlined in the ACGIH
515 TLVs and BEIs ⁸Wavelength characterization

516 **3.7 Ambient light control**

517 Iris cameras may require some degree of ambient light to detect a subject and initiate a capture
518 process. However, there are illumination scenarios which may inhibit image capture and recognition.
519 The index of refraction difference between the cornea surface and the air causes a small fraction of
520 the light incident on the cornea to be reflected. Depending on the relative angle of the incoming light
521 and the orientation of the iris and the camera, these reflections may interfere with the iris pattern
522 recorded in an image.

523 To both accommodate the requirements for device operation, and to evaluate how devices may
524 mitigate unwanted light sources, an ambient light control system has been designed to simulate the
525 influence of a range of ambient lighting environments. This system consists of a number of diffuse
526 and compact broadband sources as well as calibrated near infrared sources which can be positioned
527 at different distances and angles relative to the target location.

528 The IDQT includes simulation of three ambient lighting environments to match possible applications
529 Table 1. These are indoor without sunlight through glass, indoor with sunlight through glass, and
530 outdoor.

531 **Table 1**

Ambient Light Scenario	Lux Reading (Human Response)	NIR Irradiance (700-900nm) mW/cm ²
Indoor, no Sunlight through glass	50-500	~1.e-3
Indoor, sunlight through glass (same as outdoor in shade)	2500-5000	~1.e-2
Outdoor (consider outdoor shade+ outdoor)	25000-50000	~0.1

532 **3.8 Communication with Device Manufacturer**

533 Sources of possible bias have been identified and mitigated in this test plan to accommodate iris
534 capture devices. However, it is possible that important operational details of a given device may
535 preclude a device from being tested, and that the manufacturer may not be able to reveal
536 mechanisms to augment the test without revealing commercially sensitive information to the lab. In
537 light of this possibility vendors are contacted prior to evaluation, and given this document to review
538 to identify any areas of possible bias in the test procedure. If a device fails to produce an iris image
539 for a given IDQT test target, the details of the failure may be given to the vendor to give an

⁸ TLV and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, ACGIH 2013 (<http://www.acgih.org/>)

540 opportunity to provide a possible solution or information which may provide a cause for alternative
541 means of passing into scenario testing.

542 **3.8.1 Information useful from the manufacturer**

543 The following is a list of information expected from the device manufacture that will ensure that the
544 test represents the manufacture's intended operational use.

- 545 1. Set-up and installation instructions
- 546 2. Operating instructions
- 547 3. Directions on how to access out images and quality information if available
- 548 4. Hardware Requirements
- 549 5. Stand-off distance from corneal surface or other facial reference point
- 550 6. Operational capture volume
- 551 7. Ambient light requirements
- 552 8. Location/definition of optical axis
- 553 9. Power requirements
- 554 10. Other operational requirements

555 Any other relevant information from the device manufacturer will be taken into consideration to
556 facilitate the testing process.

557 **4 Test Procedures**

558 **4.1 Overview**

559 This section outlines the procedures for carrying out the IDQT. All but one metric involved in the test
560 is derived from the output image of the collection device, with the exception being the illumination
561 characterization. For the image based tests, after the diagnostic images are collected, they are
562 analyzed by image processing algorithms to produce output metrics which are then compared to a
563 set of qualification criteria outlined in section 5.0. The information is reported in a format that
564 includes at least sample images used in producing the metric.

565 **4.2 Pre-test preparation**

566 For each device being evaluated by the IDQT, an IDQT initiation form shall be submitted as a pre-
567 requisite to begin testing. This form is intended to be the mechanism for the device vendor to convey
568 information needed to successfully carry out the test, and to assert what the category and
569 operational mode or modes best describe the device. A point of contact from the vendor will be
570 designated to establish a technical dialog with lab facility in the event of possible technical problems
571 that may be encountered while conducting the test. A non-disclosure agreement (NDA) between the
572 testing facility and the device vendor is also initiated at the pre-test preparation stage.

573 **4.3 Data Collection**

574 The core of the IDQT procedure involves the collection of images from the six categories of test
575 targets. Before target collection begins, a check is performed to make sure that the evaluation
576 device is working according to the manufacturer’s directions, and that the output images are
577 accessible for analysis. The collection procedure is not the same for all targets, with some targets
578 requiring more angles of rotation than others, or for example the use of the ambient light control
579 shield. For each image target collected, a corresponding algorithm, or set of algorithms is applied to
580 produce the metrics used in the criteria comparison. Table 2 illustrates the relationships between
581 the targets and the corresponding output metrics.

582 Each test collection consists of 5 collections taken with 4 target orientations. A metric value can be
583 computed from single captures, so statistics can be performed through the 20 collections to estimate
584 the error of the test metrics, with possible systematics detected from the changes in rotation
585 orientation of the target.

586 **Table 2**

#	Image Quality Metric	Required targets
1	Spatial Frequency Response	60 Segment Star Pattern
		120 Segment Star Pattern
		Quadrant Pattern
2	Pixel Scale	All targets
3	Greyscale linearity	Quadrant Pattern
4	Greyscale Resolution	Quadrant Pattern
		Low contrast Star Gradient
		Feature Spectrum
5	Iris Feature SNR	Low Contrast Star Gradient
		Feature Spectrum
6	Ambient Scene Corneal Reflection Noise	Uniform Dark
		Feature Spectrum
7	Instrument Illumination Corneal Reflection Noise	Uniform Dark
		Feature Spectrum
8	Exposure Time	Exposure Time Target
9	Illumination Eye Safety	Photo-Transistor Target
10	Illumination Wavelength Characterization	Fiber Spectrometer Target

587

588 **4.3.1 Pre-Collection Setup**

589 *Procedure for device and target placement*

590 The face model is designed with a standard ¼ - 20 mount which accommodates standard tripod
591 mount hardware and COTS optical mount hardware. Using this mount, the face target is secured to a
592 vibration-controlled optical table at one end. The iris camera undergoing evaluation is mounted
593 relative to the optical targets according to the manufacturer’s directions for stand-off distance. An
594 alignment laser mounted in the center of an eye model is used to align the target system to the
595 optical axis of the iris capture camera. If the optical axis of the iris camera is not well defined or

596 specified by the manufacturer, the best estimate is chosen by the test operator, using feedback from
597 the initial try of the test target images.

598 *Note for devices too large to fit on the optical table*

599 Some iris capture devices are too large to fit on the 4'x8' optical table or are designed with the
600 notion that the subject will be walking through the capture volume. If a device cannot be placed on
601 the optical table, an alternative mounting solution will be used according to the device form factor
602 and mount feasibility. In some cases it is expected that the device will be placed on the floor of the
603 laboratory room, or using extensions to the optical table. These cases will not fully benefit from the
604 vibration control of the optical table and in the case of unexpected performance failures, root cause
605 analysis may be performed to make sure vibration is not the cause. In the case of a walk through
606 application, improvised solutions will be employed with feedback from the vendor.

607 *Procedure for excluding “failed” Captures*

608 The following are criteria which would invalidate an image for consideration in the test.

- 609 1. A capture (illumination flash and appropriate feedback) which results in no output images
610 from a device.
611 2. An output image which is not visibly recognized as a target image
612 3. An image which satisfies Chauvenet’s criterion to exclude a data point using the initial set of
613 20 images (per target) to develop baseline statistics.

614 In line with the goal of measuring “Peak” imaging performance, if there are a number of failures for a
615 given test target, attempts to recapture images will be made until a set of at least 16 images are
616 obtained with no defined outliers.

617 **4.3.2 Detailed Image Collection Procedures**

618 The following procedures are to be carried out after the device and face mount have been
619 positioned, and all manufacturers’ recommendation for operation have been confirmed. Lighting for
620 the collection uses a commercially available fluorescent light evenly distributed behind the capture
621 device with a nominal value of 100 lux, in line with the “indoor, windowless” ambient light category
622 but without significant texture in the scene presented to the target. NIR Irradiance, lux from a
623 conventional photography light meter, and spectrometer measurements from ~600-1200nm are
624 taken before data collection for each device to ensure the ambient lighting environment does not
625 significantly change from device-to-device.

626 For each test, and regardless of the mode of the test, the same type of target will be used in both
627 eyes simultaneously, with both targets being rotated together in each rotation angle iteration for
628 devices that capture both eyes from one presentation.

629 *Collection Procedure for Image Quality Targets*

630 The following steps are to be followed in the collection of the images for targets including the 60 and
631 120 segment star gradient contrast pattern, the quadrant patches target, the iris-like feature

632 spectrum target, and the square grid target. The order that the different target patterns are taken
633 does not matter.

634 For two-eye capture devices:

- 635 1. Place the cornea free version targets in each eye slot at rotation position 1
- 636 2. Perform 5 capture attempts
- 637 3. If successful, repeat 5 capture attempts for each of the other 3 rotations, if unsuccessful
638 reattempt up to 3 times for each failed capture attempt until 5 successful captures are
639 collected

640

641 For one-eye capture devices:

642 Carry out steps 1-3 above for each eye separately.

643 After analysis, and elimination of outliers, if less than 16 images remain in the qualification set then
644 recapture attempts (up to 3) will be made until at least 16 images per target are obtained, with at
645 least 4 per rotation angle.

646 *Collection Procedure for Ambient Light Qualification*

647 The ambient light test requires the patterned scene illumination hardware be attached to the optical
648 table, and the illuminated patterned scene consisting of contrast patterns which, projected from the
649 corneal surface give features between 0.2 and 2 mm as measured at the object plane of the iris
650 target (cornea surface). These patterns may interfere with iris texture. The ambient light scene is
651 designed to range in illuminance as measured from the target with 4 fixed levels (20, 100, 5000, and
652 50,000 lux). The image collection procedure is as follows:

- 653 1. Place the illuminance meter eye module in the face target, and adjust the ambient light to
654 one of the three light levels being tested.
- 655 2. With the corneal surface versions of the uniform dark eye targets in place in each eye slot,
656 follow steps 1-3 in the previous section, capturing 5 images for each of the 4 rotation angles
657 for each eye.
- 658 3. With the corneal surface versions of the Iris texture target in place in each eye slot, follow
659 steps 1-3 in the previous section, capturing 5 images for each of the 4 rotation angles for
660 each eye.

661 *Collection Procedure for Exposure Time testing*

662 Images of the exposure time target with the blinking lights powered on are used to estimate
663 exposure time. The target is validated with controlled imaging using a both a long exposure to ensure
664 that all lights are operational, and with known short exposures to confirm that the blink duration for
665 each light is 5ms. Five images from each eye need to be captured for the analysis to average out
666 effects from devices which may use progressive scan rather than global shutter modes.

667 *Collection Procedure for illumination Characterization and Eye Safety*

668 The illumination characteristics will be measured using a calibrated irradiance meter, in conjunction
669 with a spectrometer with optical apertures mounted in the face target near the iris region. The time
670 signature of the illumination sequence during the target imaging will be recorded and compared to
671 eye safety guidelines⁸.

672 **4.4 Application of Image Processing Algorithms**

673 The result of a successful image capture process for a device in a single image per capture attempt
674 mode is a total of 530 images. Considering set-up time and confirmation of the data quality, the
675 entire data collection takes about 4-6 hours. Once collected the images are processed through a
676 series of diagnostic algorithms which produce the IDQT metrics. The following subsections provide a
677 high level review of the output metrics.

678 **4.4.1 Pixel Scale**

679 The pixel scale refers to the spatial sampling rate of pixels expressed in the object plane coordinates,
680 or referenced to the scale of the iris. The units are in number of pixels/mm. This sampling rate is
681 important as it sets limits in the realm of conventional imaging as to what spatial frequencies can be
682 measured without aliasing signal. The pixel scale can be measured in a straightforward manner from
683 any image collected in the IDQT collection sequence by using the scale of the outer diameter of the
684 iris targets. These are automatically calculated through a segmentation algorithm and manually
685 checked. With the exception of the capture volume testing, the pixel scale should not vary with a
686 fixed standoff distance and this principle is used as a quality check for processing.

687 **4.4.2 Spatial Frequency Response**

688 In the ISO standardized notion of iris biometrics, identity is performed through a signal extraction
689 and matching of near infrared iris images. All the information of relevance to iris biometrics is
690 contained in the spatially varying albedo of the iris, which is recorded as greyscale image values. The
691 ability of an imaging device to measure spatially varying signals of different sizes is referred to as the
692 spatial frequency response. There are a number of standardized ways of measuring the spatial
693 frequency response from an image with a known target. The most common metrics used are the
694 modulation transfer function (MTF) using either a point source, slanted edge, or sinusoidally varying
695 patterns and the contrast transfer function (CTF) using targets with alternating bands of light and
696 dark.

697 The IDQT measures MTF using two different methods. One uses the slanted edge method (ISO
698 12233) using the edges at the borders of the quadrant pattern target. The other method uses the
699 two star target patterns to formulate a direct measurement of the CTF, which is closely related to the
700 MTF. An analysis program is run on the images and directly calculates a CTF value at each of the 60
701 patterns around the circle with 100 radial samples which provide the variation in spatial frequencies
702 to form the CTF. Low order aberrations such as astigmatism and coma can be inferred from changes
703 in the CTF values as a function of angle.

704 The output of this test are CTF curves at 12 angles to provide error estimates, as well as MTF values
705 from the slanted edge tests on the four quadrant borders. Tabulated values at 1, 2, and 3 lp/mm are
706 stated for use in the three-tiered qualification scheme.

707 **4.4.3 Iris signal-to-Noise**

708 The purpose of this test is to measure the effective iris feature signal-to-noise ratio. Measurements
709 of the characteristic iris texture from the generalized definition of an iris feature shown in Figures 5-7
710 are used to form this metric with a generalized notion of how the iris encoding and matching process
711 works. Namely the images of the iris targets are run through segmentation and encoding algorithms
712 that generate iris templates. Binary templates are created using different encoding filters across a
713 spectrum of frequencies covering feature sizes from 0.25mm to 1 mm. The filter definitions
714 mentioned in publications are included in the test, and include the log-Gabor wavelets, DCT, and
715 Haar encoders and include a mask defined by where the recorded signal strength is below a
716 threshold. For each of the 20 images collected from each eye, the template is compared to a
717 “pristine” reference template and the XOR results for each defined bit are recorded at the rotation
718 minimum based on a conventional global Hamming Distance score formed from all non-masked bits.
719 The output from the analysis is a series of 20 XOR result arrays based on a global minimum score, the
720 commensurate 20 Hamming distance scores, and the percentage of the 20 values of the total area
721 which passes the mask filter. This information is the basis for the qualification criteria outlined in
722 section 5.

723 In this case where there are no differential distortions or occlusions caused by iris dilation, eye gaze,
724 or eyelid occlusion, the genuine group Hamming distances as a function of spatial frequency are
725 directly related to the ability of a the evaluation device to record relevant iris-like contrast features
726 under a definition of signal in line with that used by iris biometrics. Because the target represents
727 real iris texture, the test can evolve in time incorporating new definitions of features and matching.

728 Preliminary testing has shown that different filter definitions give similar results as a function of
729 frequency, and this test may allow reduction to one filter type.

730 **4.4.4 Field Distortion**

731 In order to measure the field distortion the method is adapted from the ISO 9039-2008 standard
732 *Optics and photonics -- Quality evaluation of optical systems -- Determination of distortion*. This
733 method measures the error of the extra-axial image points compared to the nominal, undistorted
734 image points under the assumption that the target is not tilted relative to the sensor plane. A
735 distortion map is output from the analysis in object plane Cartesian coordinates, and in the pseudo-
736 polar coordinates after segmentation. These maps are compared to the scale sizes corresponding to
737 the three tiers of qualification, showing the fraction of area which distortion is greater than the
738 feature size.

739 **4.4.5 Greyscale Linearity, Illumination Uniformity**

740 The IDQT uses the Quadrant Step target to make a measurement of the greyscale linearity over the
741 relevant range of albedo representing the iris texture. The output metric from this test is the

742 deviation from linearity to an albedo reference (greyscale values with errors versus albedo value) and
743 the greyscale-to-albedo gain value representing the best fit to a linear model. In addition, the
744 systematic variations with position in the eye are derived from the four rotation orientations, as well
745 as the greyscale uniformity over each quadrant.

746 **4.4.6 Albedo Sampling Rate**

747 The quadrant step target, and the uniform dark target are used in a measurement of the albedo
748 sampling rate as a function of spatial scale. This is essentially based on variance measurements taken
749 over different region sizes of the uniform albedo regions in the targets, and a calibration from
750 greyscale values to albedo values considering the targets have a known albedo. The sampling rate at
751 the three scale sizes relevant to the qualification criteria at the absolute albedo of 0.12 are tabulated
752 for the report.

753 **4.4.7 Ambient Light Mitigation, Corneal Reflection Noise**

754 The surface of the cornea has a different index of refraction compared to the air which results (via
755 the Fresnel equations) in a mirror-like specular reflection. In addition to the index of refraction
756 difference, the magnitude of the reflection off the corneal surface depends on the angle of
757 reflection. Assuming the index of refraction of the corneal surface is 1.376, this surface reflects
758 about 2.6 percent of the incident light for most angles of concern for views of the iris along the
759 nominal optical axis of the eye. A point source illuminator or one with relatively small angular size
760 results in a small specular reflection spot. Sources of light with a larger angular footprint, such as an
761 un-obscured window to daylight seen in a dark room, result in larger projected area on the cornea.

762 Unwanted noise for iris biometrics occurs when the scene projected onto the cornea is of a similar or
763 slightly greater intensity of the iris pattern. The relative brightness of the iris to the corneal
764 reflection depends on the angular distribution of the ambient light incident on the cornea. There are
765 certain device design characteristics which can mitigate the effects of corneal reflection noise, such
766 as the use of narrow band optical filters matched to supplied illumination, and the illumination
767 intensity.

768 The images of the uniform dark target with the corneal surface with the different levels of ambient
769 light are used to develop a map of the scene reflected by the cornea. The maps are converted to
770 estimated equivalent albedo, or expressed in greyscale space if it is suspected that the images
771 undergo adaptive regional histogram equalization which would complicate the conversion to albedo.
772 The lowest level at 20 Lux ambient is considered the “instrument only” signature map, followed by
773 the 3 different ambient light qualification levels. These maps are compared to the nominal definition
774 of iris signal as a function of spatial scale as one input into the ambient light qualification.

775 The images collected of the iris texture target with the corneal surface are compared both back to a
776 “perfect” reference template as well as the instrument only template. The metrics are sourced from
777 the same output as outlined in the iris signal-to-noise section above.

778 **4.4.8 Capture Volume Estimation**

779 The iris-like feature target is used for this exercise. Capture attempts are made throughout the
780 capture volume as claimed by the device manufacture. If important for a given application, the full
781 suite of image collection and analysis can be carried out. For the nominal test, captures attempts at
782 the boundaries of the capture volume are carried out with the iris texture target, with real time
783 feedback matching to a reference template. Discrepancies are from manufactures claims are noted in
784 the IDQT report.

785 **5 Guidelines for Qualification Criteria**

786 The qualification criteria outlined below are chosen so if a device passes all outlined criteria for a
787 given application, it would be appropriate to proceed to human-in-the-loop scenario testing. When
788 possible, qualification criteria are formed with a foundation of algorithm performance based on
789 studies measuring the interaction between the various aspects of device-level image quality and
790 matching performance, such as those outlined in the IREX II (IQCE) study. However, as emphasized
791 throughout this document, the performance of an iris biometric system can be influenced by a large
792 number of factors beyond those specific to the peak imaging performance that is measured from the
793 IDQT procedure. This fact complicates the construction of criteria that directly correlate with the
794 matching accuracy from a real world collection. Commercial algorithms are developed in a
795 competitive environment and collectively explore a range of specific techniques and so may have
796 varying sensitivities to specific aspects of device-level image quality. It is possible that future
797 developments in matching algorithms may use information from the iris that is not currently utilized.
798 To accommodate flexibility in a developing industry, the qualification criteria presented here are
799 designed to be as agnostic to algorithm performance as possible, keeping in mind a realistic notion of
800 the information that algorithms may use in the identification process, namely the near-infrared
801 image contrast of the iris texture, and the borders between the iris and the pupil and sclera.

802 Another complication for qualification is that different applications will inevitably place different
803 performance requirements on biometric devices. For example, the requirements for a national ID
804 program, which involves large population de-duplication (N-N), will have different definitions for
805 acceptable performance relative to verification application (1-1). A device intended for enrollment
806 may have a different requirement for peak imaging performance compared to a device intended
807 exclusively for verification. The following section presents a set of qualification criteria based on the
808 metrics resulting from running the IDQT collection procedure and analysis designed to address these
809 challenges.

810 **5.1 Three Tier Qualification**

811 The IDQT qualifies devices for eye safety, and that they accurately record information required for
812 iris biometrics with an assessment for suitability considering different ambient lighting environments.
813 Considering the wide spectrum of possible applications, and to allow for the IDQT to maintain
814 relevance as the industry develops, a tiered qualification system is employed.

815 Three qualification criteria are defined to judge the ability of a device to record iris texture in three
816 spatial frequency intervals, with the base level (Level 1) being defined by the upper response
817 frequency for widely used commercial iris matching algorithms available at the time of writing this
818 document. The three levels are:

- 819 • Level I: Devices must be able to deliver images that result in a measured MTF with a
820 modulation of more than 50% at 1 lp/mm using the IDQT targets. In addition, the encoded
821 0.75mm features from the bare iris feature spectrum target must be matched with a HD
822 score of 0.1 or less to the pristine reference template for at least 95% of the collected images
823 (1 out of 20 can fail). Each Hamming distance is only valid if more than 90% of the iris area
824 passes the signal quality mask relative to the reference template mask. Out of the three
825 encoder types used, the type resulting in the best score is the one used in the evaluation.
- 826 • Level II: Devices must be able to deliver images that result in a measured MTF with a
827 modulation of more than 50% at 2 lp/mm using the IDQT targets. In addition, the encoded
828 0.375mm features from the bare iris feature spectrum target must be matched with a HD
829 score of 0.1 or less to the pristine reference template for at least 95% of the collected images
830 (1 out of 20 can fail). Each Hamming distance is only valid if more than 90% of the iris area
831 passes the signal quality mask relative to the reference template mask. Out of the three
832 encoder types used, the type resulting in the best score is the one used in the evaluation.
- 833 • Level III: This specification is included to support future algorithms capable of exploiting
834 higher spatial frequency information. Devices must be able to deliver images that result in a
835 measured MTF with a modulation of more than 50% at 3 lp/mm using the IDQT targets. In
836 addition, the encoded 0.25mm features from the bare iris feature spectrum target must be
837 matched with a HD score of 0.1 or less to the pristine reference template for at least 95% of
838 the collected images (1 out of 20 can fail). Each Hamming distance is only valid if more than
839 90% of the iris area passes the signal quality mask relative to the reference template mask.
840 Out of the three encoder types used, the type resulting in the best score is the one used in
841 the evaluation.

842 To note the tests for other metrics such as pixel scale, greyscale linearity, albedo sampling rate, and
843 field distortion are not explicitly used in a final qualification decision. However various combinations
844 of these aspects of image quality may significantly influence biometric performance. Instead of
845 making a complicated interdependent set of criteria from individual components, the IDQT is based
846 on criteria which attempt to capture the combined influences of all the potentially significant aspects
847 of iris image quality. In the case of a failed qualification, the individually reported metrics can be used
848 to give information back to vendors to guide them in improving their devices to meet the desired
849 qualification criteria.

850 **5.2 Ambient Light Environment Qualification**

851 In addition to the 3 level qualifications, the ambient light tests are used to qualify devices in three
852 different lighting environments. These are: 1) indoor office without windows, 2) indoor with
853 windows, and 3) outdoor direct sunlight (see Table 1). The fraction of cornea reflection noise from
854 the device illumination, either from the primary specular reflection or the secondary reflections from

855 the nose, is tallied separate from that of the controlled artificial ambient light source. A device can be
856 qualified for each of the three ambient light criteria at each of the spatial frequency-based level
857 tests. Qualification is passed if over 80% of the iris texture information is able to produce a match
858 and below the albedo noise criterion to a reference template for each of the 20 images collected in
859 each set relative to the “instrument only” set, with the “instrument only” set needing no less than
860 90% of the area matchable relative to the noise free reference template and below the albedo noise
861 criterion for each spatial frequency under evaluation. For example, a level III, outdoor ambient
862 qualification would need to accurately record the encoded 0.25mm features over at least 80% iris
863 area relative to a pristine template.

864 5.3 Application Relevant Device Classification

865 A wide variety of applications are possible for iris biometrics. Formal qualification for particular
866 programs would be specified externally by referring to this document. The IDQT uses the device
867 classifications that are asserted by the vendor upon application for device qualification. If there are
868 any discrepancies between the asserted device category and the experience using the device during
869 evaluation, this will be noted in the evaluation report. The following categories are defined as:

- 870 1. Mobile Non-Contact
- 871 2. Mobile Contact
- 872 3. Stop and Go at a Distance
- 873 4. Walk Through
- 874 5. User Position to Fixed Focus

875 In addition to the 5 application specific categories, additional device categories are noted based on
876 the output. For example, two eye capture versus single eye capture, are not specifically tested, but
877 are recorded as a part of the IDQT reporting process based on vendors claims.

878 5.4 Root cause analysis for Elemental Metrics

879 The qualification criteria are based on the “bottom line” iris texture SNR metric, as well as the MTF
880 metric, however a larger number of other lower level metrics are produced from IDQT testing. These
881 are used to assess the relative margin strengths and weaknesses of the evaluated devices. The DHS
882 S&T/HSARPA reserves the right to distribute the IDQT root cause analysis back to the vendor on a
883 case-by-case basis to provide information useful as feedback for how they may improve their product
884 relative to meeting the IDQT criteria.

885 Appendix A Example Report Format

886 **Device ID:** 123456

887 **Evaluation Dates:** SEPT. 14-15, 2013

888 **Asserted Device Category:** Mobile Non-Contact, Two eye capture, Single image per capture per eye

889

Criterion	Measured Metrics	Result
Level I, II, III	MTF:	

Ambient Indoor No Windows	<p>Mod @ 3lp/mm = 0.25 Mod @ 2lp/mm = 0.51 Mod @ 1lp/mm = 0.92</p> <p>IRIS TEXTURE SCORES: <HD> level I = 0.04 with 95.4% unmasked <HD> level II = 0.06 with 95.3% unmasked <HD> level III = 0.11 with 96.8% unmasked</p> <p>AMBIENT LIGHTING NOISE SCORES: Level I - 98.4% to Ref., 99.0% to Inst. Only Level II - 95.3% to Ref., 98.3% to Inst. Only Level III – 89.1% to Ref. 92.0% to Inst. Only</p>	<p>Qualification at: Level II - Ambient Indoor No Windows</p>
Level I, II, III Ambient Indoor Windows	<p>MTF: Mod @ 3lp/mm = 0.25 Mod @ 2lp/mm = 0.51 Mod @ 1lp/mm = 0.92</p> <p>IRIS TEXTURE SCORES: <HD> level I = 0.05 with 95.2% unmasked <HD> level II = 0.09 with 94.5% unmasked <HD> level III = 0.23 with 92.1% unmasked</p> <p>AMBIENT LIGHTING NOISE SCORES: Level I - 97.2% to Ref., 98.6% to Inst. Only Level II – 90.3% to Ref., 94.3% to Inst. Only Level III – 75.2% to Ref. 82% to Inst. Only</p>	<p>Qualification at : Level II - Ambient Indoor Windows</p>
Level I, II, III Ambient Outdoor	<p>MTF: Mod @ 3lp/mm = 0.25 Mod @ 2lp/mm = 0.51 Mod @ 1lp/mm = 0.92</p> <p>IRIS TEXTURE SCORES: <HD> level I = 0.11 with 94.2% unmasked <HD> level II = 0.15 with 95.2% unmasked <HD> level III = 0.31 with 96.1% unmasked</p> <p>AMBIENT LIGHTING NOISE SCORES: Level I - 83.2% to Ref., 86.6% to Inst. Only Level II – 74.3% to Ref., 78.3% to Inst. Only Level III – 63.7% to Ref. 72% to Inst. Only</p>	<p>No Qualifications for Ambient Outdoor</p>
<p>Eye Safety Check: Continuous Illumination during exposure (no pulse) Single peak wavelength @ 811nm, FWHM of 30nm, Irradiance on target of 0.12 mW/cm² EYE SAFE</p>		
<p>Nominal Standoff Distance: 16.4 cm</p>		
<p>Exposure Time Range:</p>		

20ms +/- 5ms

Notes:

No complications encountered for device set-up

Well documented operation instructions with supplied demonstration application

No capture failures with IDQT targets

890

891 **Raw Image data tar file:**

892 IDQT_SEPT152013_Device_12345.tar

893