UDK: 777.31:535.241.46
COSATI: 17-05
doi: 10.5937/str2102003L

Low Light Level Digital Camera Quality Assessment

Branko Livada [1)]
Dragana Perić [1)]
Saša Vujić [1)]

Imaging sensor development results, achieved in the past four decades, provide increased camera capabilities both in day and night conditions. Due to advanced camera performances, we are experiencing a wide application of the imaging sensors in various areas, e.g. machine vision, mobile technology, autonomous vehicle driving, smart city scenarios, and scientific imaging. Low light level sensitivity, supporting camera night vision capability, leads to new applications in the security systems. Accordingly, the new needs of the camera testing procedures appear. Advanced camera performances also require a new approach to imaging sensor and camera testing and parameter definition. The short review of the current achievements in the area of low light camera technology developments is presented as a basis to illustrate the importance of their application and proper metrological support development. The review of the most important low light camera parameters and related measurement and testing methods is set to point out the needs for new low light camera testing procedures development.

Key words: **Low Light Level Camera Technology; Nigh Vision; Camera quality parameters, Camera Testing Procedures; Contrast Transfer Function; Camera Sensitivity, Camera Resolution.**

Introduction

IMAGING sensor manufacturers, camera developers and imaging system manufactures nowadays, usually belong to the different organizations. In addition, users need to have a clear sense regarding quality control, and applicability of the imaging devices. This is one more reason to have clearly defined camera parameters providing a good understanding between all involved parties in the camera production and application chain.

Imaging sensors are usually well adapted to the selected spectral band that is illustrated in Fig.1. An image is formed using reflected radiation – from natural or artificial irradiation sources (UV, VIS, NIR and SWIR) or IR thermal radiation (MWIR, LWIR).

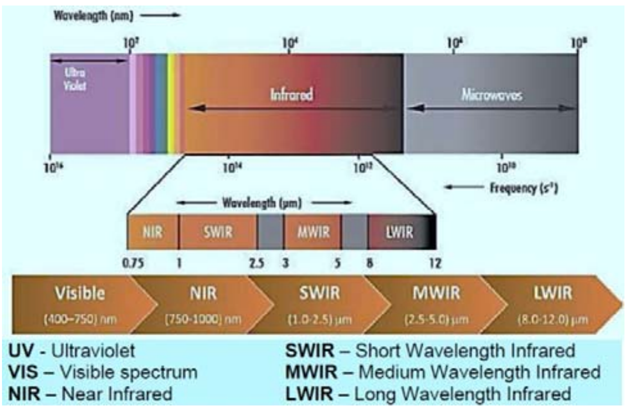


Figure 1. Night vision technology related spectral regions

Low light level – LLL sensing provides imaging during the low visible light conditions, existing during night. Night vision technology started development with well-known image intensifier technology [1] and later expanded to thermal imaging.

The increased imaging sensor low light level capabilities and various options, provide electronic imaging device (camera) as a solution for day light and night conditions at the same time having even color imaging capability during the night. The typical values for night illumination levels are listed in Table 1 [2]. If these levels are compared to day light illumination (up to 80000 lux) and normal office illumination (200 lux-1000 lux) it is clear that the new approach in LLL camera evaluation is necessary, due to metrological support related to low illumination levels.

The LLL imager performance evaluation appears as a new challenge that is not universally resolved through standard camera measurement methods definition. In the current practice the measurements are conducted according to the best knowledge about electro-optical (EO) imager testing [3 – 5] and night vision metrology [6] developed for image intensifier devices [7]. The evaluation methodology is usually adapted in accordance with the imager's type and aimed application goal.

The goal of this paper is to make a short review of the LLL imaging technology pointing out the basic characteristics and related assessment methodology. As a starting point the short review of the basic performances of the imaging cameras is presented. Also, illumination source properties that could be used for LLL imaging have an important role in the testing methodology development. The most known measurement set-ups for visible and IR cameras applicable for LLL camera testing are used as a basis to define the key issues that should be resolved for LLL camera metrology purposes. This article contains the results of the analysis generated during our study efforts to develop a new low light level camera testing set-up and methodology aiming improvements of our EO laboratory capabilities.

In the discussion section the camera evaluation LLL methods and related metrological issues are overviewed.

[1)] Vlatacom Institute, Milutina Milankovica 5, 11070 Belgrade, SERBIA
Correspondence to: Branko Livada, e-mail: branko.livada@gmail.com

Table 1. Night illumination levels

Illumination Conditions	Night level 1	Night level 2	Night level 3	Night level 4	Night level 5
	Full moon	Half moon	Quarter moon	Clear Starlight	Overcast Star-light
					
Range illumination [mlux]	40-1000	10-40	2-10	0.7-2	0-0.7
Test room illumination [mlux]	**100**	**15**	**4.3**	**0.9**	**0.4**

Night vision and low light level illumination sources

Low-light imaging is a technology used to improve visibility in dimly lit environments where sensitivity of the human eye is poor. This technology uses residual radiation that could not be detected by an un-aided human eye because it is under human eye sensitivity level in the visible region, or generated in the other spectral regions. This type of illumination conditions appears mainly during the night. Thus, the commonly used term is “night vision” technologies and it covers: low-light level (LLL) imaging, near-infrared (NIR) imaging, short wavelength infrared (SWIR) imaging and thermal (medium wave infrared (MWIR), long wave infrared (LWIR)) imaging. LLL, NIR and SWIR imagers use reflected natural or artificial illuminator sources as a scene illumination source. For that reason, the same testing methodology is applicable to all three of them. In addition, some scientific and biomedical applications use weak or luminescence sources for image generation purposes.

Thermal imagers (MWIR and LWIR) use object emitted thermal radiation. All night vision technologies transform an invisible image into a visible using different techniques. It means that evaluation methodologies of all night images should be similar but differences appear in the evaluation of the conversion efficacy and testing source design and metrology [8, 9].

Natural illumination (irradiation) sources

The knowledge about night time illumination (irradiation) sources is a starting point in the night vision technology understanding. The physical quantity, describing the amount of visible light energy falling on a scene [10], is called illumination and measured in lux [lm/m2]. The level of illumination varies during the day from 100.000 lux (bright sunny day having spectrum as illustrated in Fig.2), 500 lux (bright office illumination) to 0,1 mlux (moonless overcast starlight – having a spectrum presented in Fig.3 and typical illumination levels presented in Fig.4.)

Human eye is adapted for vision during day light, so illumination is measured using photometric quantities that are weighted with human eye spectral sensitivity. In the NIR and SWIR part of the spectrum these quantities are not applicable, but describing the irradiation levels in this part of the spectrum using photometric units has only some qualitative, descriptive sense.

The moon light is a primary illumination source during the night time (see Fig.3), but illumination level is changing according to the phase during lunar cycle. Star light and sky scattered light is the lowest natural illumination source (night sky glow as illustrated in Fig.5) [11-14]. The night sky glow spectral radiance curve clearly shows why imaging sensors in SWIR region provide capability for good night vision imaging.

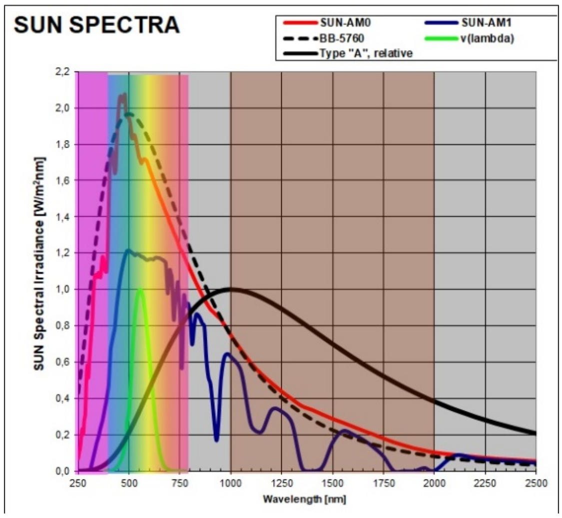


Figure 2. Sun spectrum (AM0 – out of atmosphere; AM1 – at sea level) and human eye sensitivity

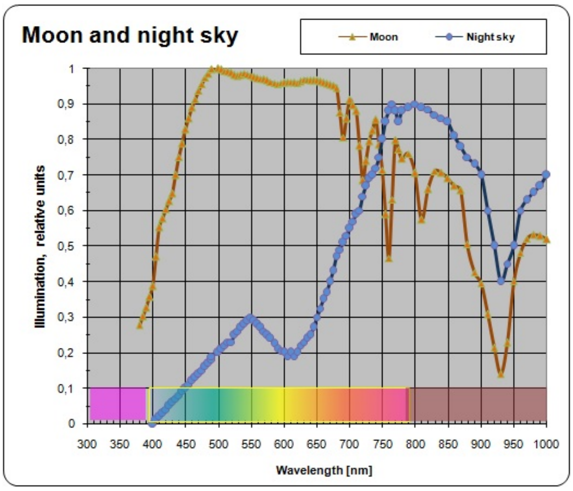


Figure 3. Night illumination due to the moon and sky

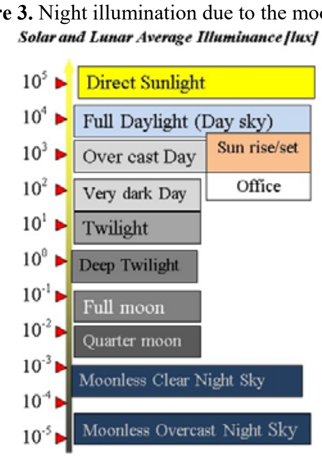


Figure 4. Solar, lunar and sky illuminance levels

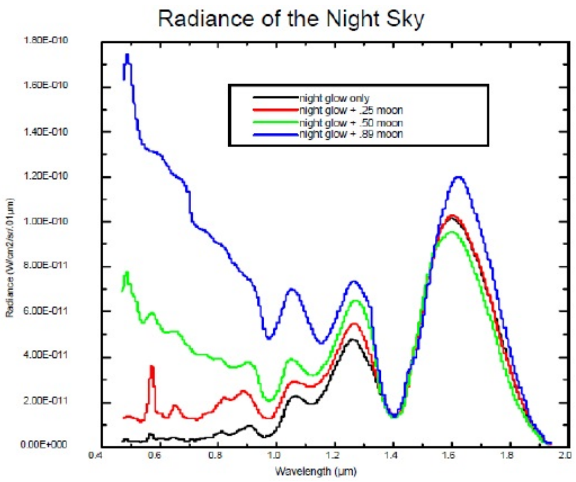


Figure 5. Night sky radiance [11]

Artificial test sources and metrology

Photometric standard source (Type A) [10] based on the application of stabilized incandescent bulb (tungsten wire) usually using quartz envelope (quarts-halogen) operating with predefined color temperature (2856 K) is widely accepted as the illumination standard in the visible spectral region. The relative spectral radiance distribution is presented in Fig.6 and compared to human visual system and SWIR InGaAs detector typical relative sensitivity. This comparison shows that this type of source could be suitable in the both VIS (NIR) and SWIR spectral region. In the VIS region photometric quantities related to integral light energy weighted by eye relative spectral sensitivity are used, and related metrology is established and well developed. In that case the well-known and widely accepted measurement unit for scene illumination is ***lux***.

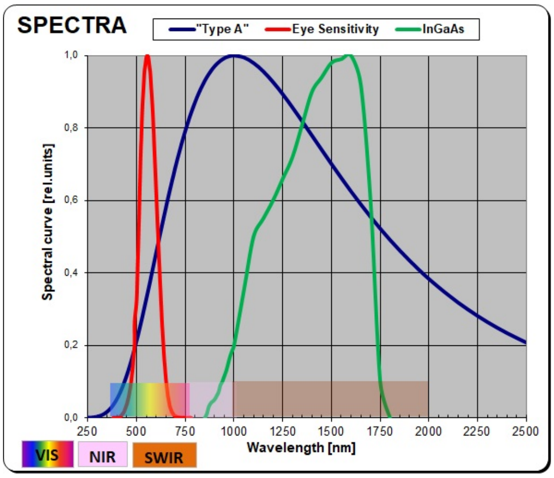


Figure 6. Test source Type A relative spectral curve compared to human visual system relative spectral sensitivity and typical InGaAs – SWIR detector relative spectral responsivity

Following the increased importance of the SWIR sensor application and potential similarity in case when the whole SWIR region used the researchers suggestion [15 - 17] to use analogy with photometry and to use a new measurement unit for SWIR irradiation, ***swux.*** The definition of the swux unit for SWIR irradiation and analogy with lux is illustrated in Fig.7. The equivalent SWIR irradiation measurement radiometer is designed using similarity in design as photometric measurement instrument lux-meter, and used for SWIR irradiation measurements. The measurement results for the selected illumination conditions are presented in Table 2 compared to related photometric values [18].

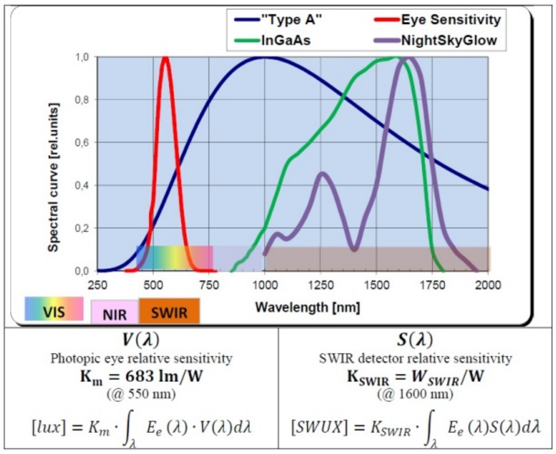


Figure 7. Comparison of the photometric units and new SWUX radiometric unit definition [17]

Table 2. Illumination level comparison

Illumination conditions	*Illumination Level*	
	[swux]	[lux]
Direct Sunlight	2,8 10^7	8,8 10^4
Overcast Daylight	4,6 10^4	900
Full Moon	97	0,1
Quarter Moon	44	1,1 10^{-2}
Clear Starlight	38	1,2 10^{-3}
Overcast Starlight	3,8	1,2 10^{-4}

Low light camera technological options

Cameras sensitive in the visible spectrum range are realized using CCD (Charge Coupled Device) and CMOS (Complementary Metal Oxide Semiconductor) technology [19-27] can be modified to obtain low light functionality. This is done by changing the primary technologies in order to increase the signal to noise ratio in the following way:

Electron-multiplying CCD (EMCCD) camera utilizes special structured frame transfer CCDs that have two areas – the sensor area which captures the image and the storage area where the image is stored and photo-generated electrons are electronically multiplied prior to read out. This technology combines CCD imaging characteristics (e.g. high quantum efficiency, low dark current, excellent uniformity, and low pixel cross talk) with high speed, low power and ultra-low read-out noise of the CMOS technology.

Intensified charged coupled device (I-CCD) – use image intensifier tube as the first stage. Its screen is optically coupled with CCD imaging sensor. The image intensifier screen has bigger area than the image intensifier sensor sensitive area, so they should be optically coupled. Optical coupling using relay optics is characterized by a good MTF, but it is bulky and involves a high loss of light. Using fused fiber optics between the screen of the image intensifier and the image sensor surface is a very efficient coupling method. If a straight fiber-optic is used, only that part of the intensifier that corresponds to the image area of the sensor is utilized. A better approach is to use a demagnifying tapered fiber-optic bundle whose input and output match respectively, the output of the intensifier and the input of the sensor. The advantages of this way of coupling are low light losses plus a compact construction.

Scientific complementary metal oxide semiconductor (sCMOS) – in basis uses CMOS sensor with a pixel architecture and geometry designed specifically to enhance low-light level imaging. Pixel size is increased for higher sensitivity of the camera. Image processing electronics is designed to achieve low read out noise.

SWIR imaging sensor

Cameras sensitive in SWIR (0.9 – 2.7 µm) spectrum essentially are not low light level cameras because of their wide spectral sensitivity mainly in the IR band, but it can be used for night observation because they have some sensitivity in the visible region and they are very sensitive in the SWIR region where night sky glow exist. Night vision with SWIR detectors in high gain mode is possible with natural night sky illumination.

Due to the importance of the SWIR technology [28-30] we will consider it as a low light level image sensor that should be evaluated in a similar way.

Digital imaging camera quality assessment

Imaging camera is considered a device comprised of optical image forming system (usually lens), image sensor placed in the image forming plane (usually focal plane array), signal and image processing electronics, as illustrated in Fig.8.

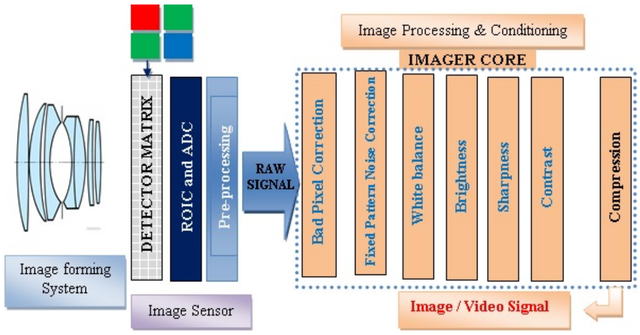


Figure 8. Generalized camera architecture

Imaging sensor development results in the past four decades provide an increased camera capability both in day and night conditions. Due to the advanced camera performances we are experiencing a wide range of application of the imaging sensors in various areas such as machine vision, mobile technology and smart city. The camera basic parameters and measurement methods are considered in literature [3]. Also, selected specific and advanced measurement methods are already discussed [30-33]. Some of the camera parameters and measurement methods are defined in related standards [34-37]. Low light level sensitivity, supporting camera night vision capability, leads to the new applications in the security systems. Accordingly, the new needs of the camera testing procedures appear.

Imaging sensor basic parameters

Advanced camera performances also require a new approach to imaging sensor and camera testing and parameter definition. Camera sensitivity and resolution are limited with imaging sensor pixel structure and size, so there is always a trade-off between them [39]. It is important to point out that illumination (irradiation) on the focal plane is the most important factor to count on when the performances are measured, and it is the connection point between camera parameters and imaging sensor parameters.

The selection of the key imaging camera and imaging sensor parameters is listed in Table 3. In this paper only selected parameters and measurement methods related to resolution and low light level operation will be discussed. Imaging sensor parameters are well defined in EMVA 1288 standard [37].

Table 3. Camera and Imaging sensor key parameters

Camera parameters	Imaging Sensor Parameters
Resolution (limiting resolution, center, corners)	Detector type, number of pixels, focal plane dimensions
Light sensitivity (Sensitivity threshold)	Effective Pixel distance (pitch) and pixel size (micron)
Noise, signal to noise ratio	Spectral sensitivity, spectral bands
Dynamic range (related scene contrast)	Quantum efficiency (electron/photon)
Color reproduction properties	Shutter options and readout timing
Sharpness	Bad pixels
Operation conditions	PRNU – Pixel Response Non Uniformity

Imaging camera basic parameters

The camera **resolution** is described as its ability to reproduce fine details in an image. The camera resolution could be defined as limiting resolution following the predefined criteria. To provide a better image usability it is important to have a good resolution over all image areas.

The imaging sensor response depending on the illumination level is expressed through the light sensitivity parameters. One of the most important is the threshold **sensitivity** defined as a minimal scene illumination required to generate the usable image. It is not easy to define and evaluate the threshold sensitivity due to the following reasons:

a) it is complicated to set and control scene low level illumination;
b) setting image usability criteria highly depends on application;
c) it is often subjective when a human observer is involved;
d) in case when the image is presented to the observer the influence of the display properties to projected image is hard to isolate.

Image noise and signal to noise ratio are the parameters that could be objectively extracted from the image (video) signal. Also, these parameters are usually a part of the objective measurement procedures related to the image resolution and sensitivity measurement. Imaging signal could have limiting range defining image low (dim) or high (bright) levels limiting scene radiance **dynamic range** that could be reproduced in the image. The imaging sensor usually has a linear light response, so the camera is not able to reproduce high luminance (radiance) level in the scene, sometimes causing saturation in the image.

In case of color imagers the proper **reproduction of the colors** in the scene should be evaluated.

Image sharpness as a part of image details resolution is an important but complex parameter to be defined and evaluated. It is closely related to the image contrast and imager contrast transfer function and imager blur distribution caused by the image forming system aberrations and pixel cross talk.

The dependence of the imaging system parameters on **operation conditions** (temperature, weather conditions) shows where application limitations are. Especially, the influence of **weather conditions** is the most important for user but also the hardest to evaluate through measurements or modeling.

Image quality metrics

The main function of the imaging system is to generate the scene information data and present them to the human observer or image processing system to extract important scene structural data. Therefore, a measurement of structural distortion should be a good approximation of perceived image distortion. Depending on image application the quality (usability) of data could be judged and quantified. So, the image quality appears as a common sense term. Yet, it is not easy to define a unique metric to express the image quality because it depends on the imaging system purpose [40, 41]. Also, the image quality assessment could be subjective (using observer's judgement), or objective (using measurement results) [42, 43].

The objective image quality metrics defined for the image processing algorithms optimization success motivated a wider application of the image quality in high quality imaging system comparison. One of the well-known efforts is the definition of the General Image Quality Equation – GIQE [44, 45] related to the aerial imaging system application and connected with the National Imagery Interpretability Rating Scale – NIIRS. Aerial and space based surveillance systems are complex in design and very expensive so developers require a tool that will accurately predict NIIRS performance prior to building and testing a new sensor system. The GIQE was developed to provide predictions regarding to a small detail resolution and involve influence of the required resolution parameters, edge response (MTF [46]) imager noise and signal to noise ratio. The design of the imaging system is the outcome of many trade studies, including the image quality within the real world limitations and their performances influence to applicability prediction (range for target perception). During the design process application of the GIQE connecting imager performance parameters and key task requirements could be useful [47].

In case of the low light digital imaging devices, the resolution is one of the important parameters, but sensitivity threshold limits also matter, so the image quality is not sufficient to predict the overall application range.

Imaging camera performance models

An accurate and properly tailored imaging camera performance model can greatly reduce the development time and cost associated with fielding new systems. An important part of an imaging system performance modeling, is accurate and well controlled imaging sensor measurement [48, 49]. On the other hand, the imaging sensor performance model outcome should provide parameters that could be evaluated in the laboratory and extended to the field testing of the imaging system. It should be clear that only the field testing ultimately validates the imaging system performances. In addition, the human observer performances should be incorporated as important part of the imaging chain. Because of that image perception the criteria development should be an important part of any model.

In case of the color imaging sensor [48, 50], a proper color balancing can make the imaging sensor model more complicated. It is normal to expect that imaging devices, such as cameras, aimed to operate in similar light levels like human visual system should provide image properties suitable to human eye. In case of the low light level conditions where human visual system cannot be used there are new imaging sensors that are able to convert residual visible light or radiation generated in the invisible part of the spectrum to the visible image. In that case the generated visible image should be suitable for human visual system. Most of the theories, measures, models, and methods in color science are developed for intensities optimal for human visual system.

In case of the low light imaging the sensor models [51-53] are based on the MTF (Modulation Transfer Function) and CTF (Contrast Transfer Function) for discrete systems. That is a good orientation because those parameters can be measured in the laboratory and can be extended to the field related evaluation. Specificity of the SWIR imaging sensor using laser illumination requires a modification of the early developed models [54].

Imaging camera measurement methodology

The most important camera parameters are connected with camera resolution and sensitivity. The common factors involved in any measurement method regarding these two groups of parameters are application of the test target designed in accordance with the requirements and proper illumination.

Measurement methods

Basic measurement set-ups could be grouped in two basic groups:

a) application of a test pattern projector (collimator) and controlled pattern illumination as presented in Fig.9(a), (b);
b) reflective or transmissive pattern – target and controlled illumination observed directly by the camera, as presented in Fig.10(a), (b).

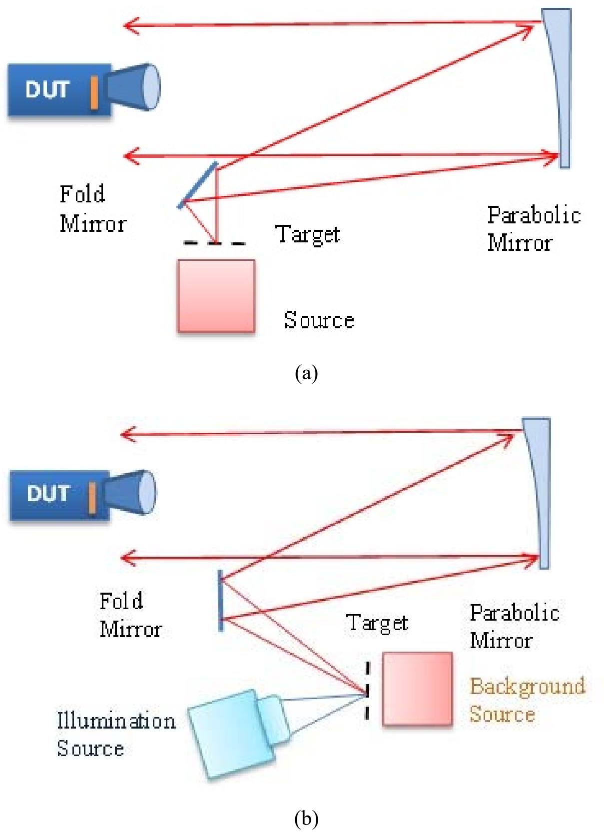
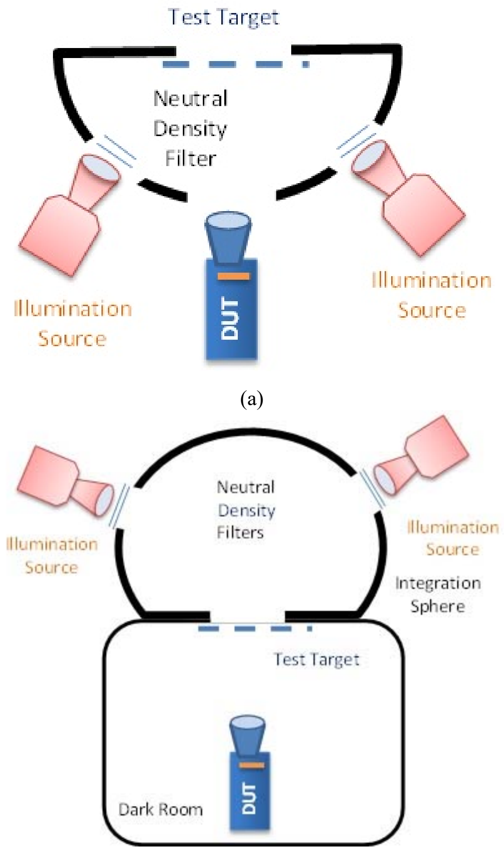


Figure 9. Camera evaluation set-up using collimator as a test image projector (a) transmissive target and back illumination; (b) reflective (semi transmissive) target using combined back and front illumination

Using these set-ups, the standardized measurement methods for resolution measurements are designed and applied in practice:

- **MRC** – Minimum Resolvable Contrast [35] linked to the visibility of a 3-bar USAF-1951 pattern and resolution limit definition for visible cameras and night vision devices based on image intensifier. The measurements are based on the application of the variable contrast target or dual illumination source. The same methodology and measurement set-up is applicable for SWIR sensors measurements [55, 56]. The measurement results could be used for imager range estimation, but additional processing

could be complicated and depends on predefined requirements.
- **MRTD** – Minimum Resolvable Temperature Difference [57-59] uses four bar test target for resolution limits measurements for thermal imagers. This is a key parameter for IR thermal imagers [60], and it is used for IR imager range estimation following standardized procedure and conditions [61].
- **MDSP** – Minimum Difference Signal Perceived [49, 62] – using visibility data of a 4-bar target the perceived signal difference is calculated. This approach intends to provide objective measurement method, but it is still not standardized. It is incorporated in the imager modeling software. The purpose of this parameter definition is to find the imager resolution parameter that is independent of the imager type.
- **TOD** – Triangle Orientation Discrimination [32, 33, 63] is a novel method that uses oriented triangles (see Figure12), as test targets to get data regarding imagers resolution. The same test pattern shape could be used for thermal imager, visible and SWIR camera, and image intensifier (low light level) imagers.
- **MDTD** [2, 22] – Minimum Detectable Temperature Difference based on the application of low spatial frequency target (usually square) for signal to noise measurements. The threshold temperature difference is defined for signal to noise ratio equal to one.



(a)

(b)

Figure 10. Camera evaluation set-up (a) reflective target and front illumination; (b) transmissive target and back illumination

Resolution is a measure of the resolvability of two close point objects [64-67]. This definition is fundamental and based on the application of the Rayleigh criteria in imaging system analysis models. Resolution can be determined through analysis of the device spatial frequency response like MTF – (Modulation Transfer Function).

In case of staring digital imaging systems the resolution is determined by different factors: (a) optical resolving power limits of the image forming system determined by aberrations and/or diffraction; (b) imaging sensor structure (pixel size and cross-talk, signal readout) [64] and imaging signal processing – sampling. From the observer point of view, it is good to know a limiting spatial frequency derived from resolution power, but the visual perception of the objects in the image is also important and not so easy to evaluate. Also, the simplification of testing and certain level of universality for different applications are important, too. The widely accepted approach is to use specially designed test pattern and get resolution related parameters through generated image analysis.

Camera resolution could be checked using Philips star test pattern [68] presented in Fig.11(a) that allows evaluation of the threshold spatial frequency and influence of the lens aberration or distortion at the same time. One of the most popular test patterns is USAF 1951, presented in Fig.11(b). This test chart integrates resolution evaluation in horizontal and vertical direction and simplified evaluation of target recognition. Foucault – Bigourdan test chart presented in Fig.11(c) originally developed for resolving power of astronomical telescopes allows resolving power evaluation in horizontal, vertical and diagonal direction. It is not so much popular as a test chart but basic design principles are incorporated in lot of test charts developed after.

The development of the TV technology initiated development and standardization of the integrated test charts. Some of them are presented in Fig.12 (a) and (b). The appearance of the color cameras generated development of the color fidelity test charts (See Fig.12 (c)). Consumer oriented imaging devices (camcorders and cell phone camera) are evaluated using specially developed integrated test charts. The most representative is presented in Fig.12 (d). All these test charts tend to provide a simplified but accurate enough methodology for camera quality evaluation.

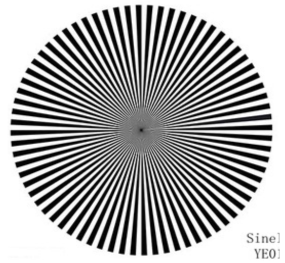
There is a lot of camera resolution testing using simple test set-up as in Fig.10, test patterns are relatively complicated providing several different camera parameters through the analysis. The examples of these test patterns are presented in Fig.12. Triangle orientation discrimination – TOD test target (see Fig.13) could be used for the same purpose for testing of the night vision devices.

Imaging camera threshold sensitivity measurement methods are still under development but we will mention several that are successfully applied in some special cases.

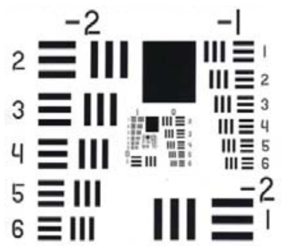
Sensitivity threshold test method [23] for visible and low light cameras has not been standardized yet.

The basis for the development of methodology for sensitivity threshold testing is based on the experience from the image intensifier devices testing methodology [68-73] and MDTD testing methodology. The fundamental limit for the image quality evaluation when image signal has a low value is imaging sensor noise, so sensitivity threshold value is set according to the imager noise.

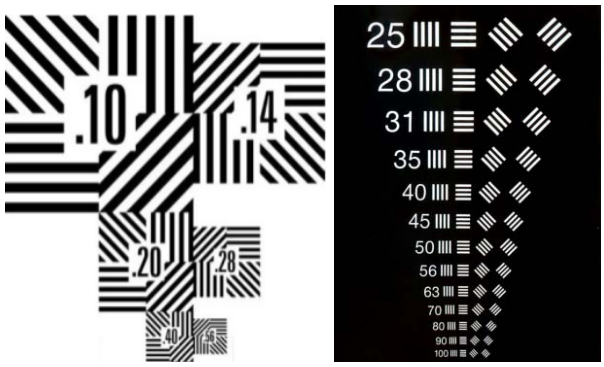
It is not easy to define a dominant noise source in the imaging sensor, and it is even harder in the camera noise case. Imaging sensor dark current noise is generally unavoidable and depends on temperature. In addition, read out noise combined with spatially distributed fix pattern noise complicate the noise level definition. In case of FPA (focal plane array) imaging sensor the PRNU (photo response non-uniformity) complicates the image signal value definition. In addition, the image preprocessing built in image sensor chip has a basic function to provide an automatic correction of deviations in the sensor array (bad pixel correction and responsivity equalization) and exposure time optimization. In case of low imaging signal value, long exposure times are necessary when sensor spatial inhomogeneity and dark current dominates as noise sources. Imaging sensor manufacturers try to correct the most of deviations on the sensor level and incorporate solutions in the image preprocessing algorithms, in order not to have the influence of camera integrator to the imaging sensor operating conditions. For that reason, the evaluation of the imaging sensor is very important. Fortunately, there are some successful standardization efforts [37] related to the imaging sensor and consumer camcorders [38]. The consumer camcorder standard is already outdated and not applicable to modern digital image sensor.



(a)



(b)



(c)

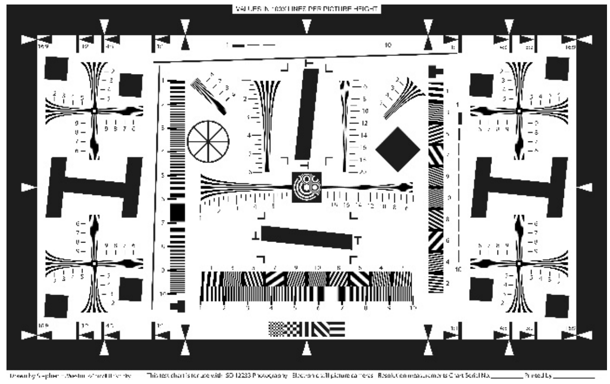
Figure 11. Camera resolution commonly used test targets: (a) Phillips star target; (b) USAF 1951; (c) Foucault – Bigourdan resolution test

Some other the efforts in the camera threshold sensitivity methodology definition as Axis MMI method [74], and methods based on signal to noise ratio measurements, are still not developed enough to be accepted as the standardized method. On the other hand, the importance of the threshold sensitivity is not equally important in all applications, so the evaluation methodology could be different depending on application.

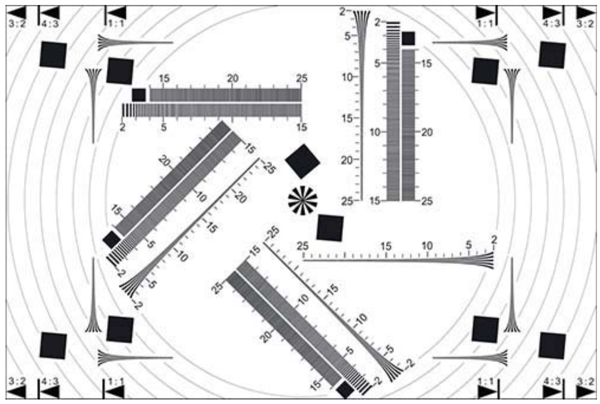
The image intensified CCD camera evaluation methods involve combination of the methods listed [75] and based on the analysis of the images generated using USAF 1951 target under different levels of illumination. The evaluation of the EMCCD camera under extreme low illumination and low operating temperatures could achieve higher maximum pixel rate, while maintaining the same low background signal level and image quality close to that achieved using photon counting method.

Mobile phone camera evaluation at low level illumination [76, 77] is important because of wide application and this capability could be important selling point for cell phones. The standard ISO 12233 and TE42 target (see Fig.12 (a) and (d) are used in testing.

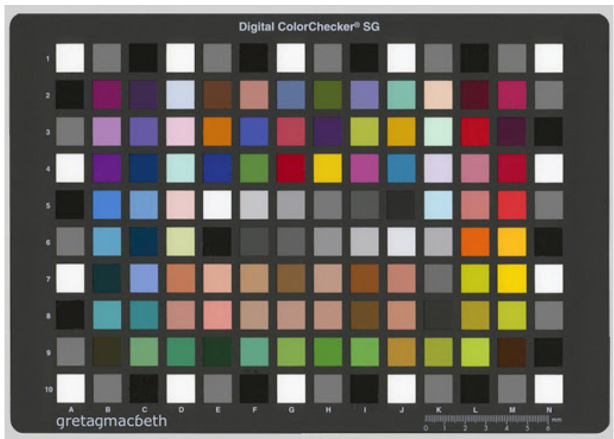
In some cases the Digital Still Camera - DSL [78] could achieve low light capability according to the increased pixel size. The influence of the exposure time, illumination level on noise, resolution and color properties was conducted according to the CEA 639 [38] and application of the TE42 test image.



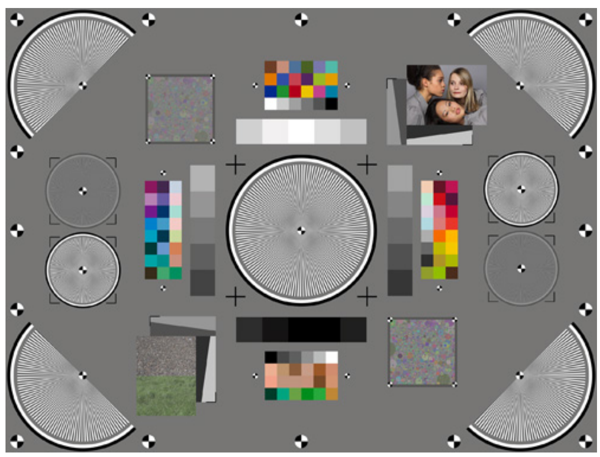
(a)



(b)



(c)



(d)

Figure 12. Camera testing targets (a) ISO 12233; (b) CIPA TE252A; (c) Macbeth Color Checker chart; (d) TE42- cell phone and camcorder

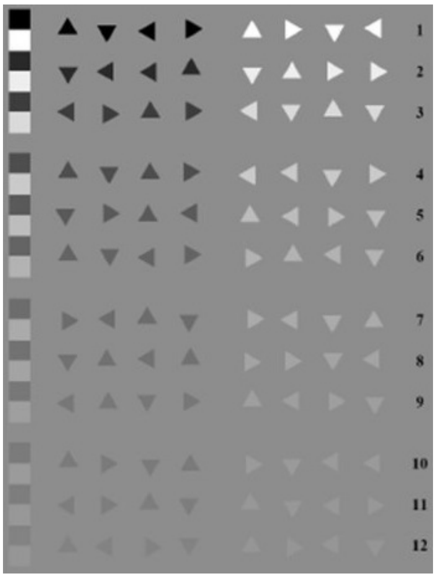


Figure 13. The example of the triangle orientation definition (TOD) test target

Advanced EO imager testing [79] system involves a lot of automatization in testing procedures trying to deliver the universal software control solution covering several different systems.

Wide Dynamic Range – HDR camera [80] evaluation set-up involves adapted test chart having areas with higher number of gray levels and using light box that is able to generate illumination up to 100000 lux. In that case cameras that do not have good enough HDR in some areas of test image produces a very bad image. There is a lot of work to develop proper testing procedures according to the camera applications.

SWIR imager testing [81] advance is based on introduction of the new radiometric quantity for description of irradiation in SWIR region based on weighting with spectral sensitivity curve of SWIR InGaAs detector on the similar way as photometric quantities are derived by weighting with human eye spectral sensitivity.

Standardization in measurements and metrology

The wide camera applications and design complexity cause a lot of standardization efforts to regulate different aspects of camera application environment.

Camera metrology is well developed area [6] but nowadays there is a lot of work to improve camera measurement and evaluation methods following the area of camera applications. There is a need for new and improved measurement methods developments in the area:

- Imaging Sensor metrology and testing standardization
- Camera evaluation methodology in LLL condition, as a part of quality control

Also, general metrological support (radiometry and photometry of radiation test sources) will need a new and advanced methodology. It will be continuous task joining efforts of the imaging sensor and camera manufacturers, and test equipment manufacturers. In addition, camera device users should improve knowledge regarding image perception criteria and definition of the camera critical parameters and their values that are important to aimed application.

Discussion

Standardized measurement methods should be carefully defined in order to be:

- ***Reproducible*** – Everyone should get same results if defined set-up and methodology is used.
- ***Robust*** – Insensitive to small changes of instrumentation and geometry.
- ***Unambiguous*** – Should be described clearly and easily understood.
- ***Extensible*** – Should be applicable through different camera types and usable for recalculation of other selected parameters.
- ***Distinct*** – The name of the procedure should not be confused with some other procedures.
- ***Simple*** – Does not require highly specialized and complex equipment and specially trained personnel.

In addition, measurement methods should be compatible with camera modeling software tools.

The methods that are using collimator are usually more time-consuming but provide more capabilities especially for imagers MTF – Modulation Transfer Function measurements, resolution and noise characteristics. The methods using test images are more suitable for routine production quality control methods.

Controlled illumination is the key for any camera testing procedure in both cases, when image projector (collimator application) and illuminated test image are used.

For the low light level camera testing the metrological environment is very important. It should provide a proper realization of the key measurement units (photometric, radiometric).

It will be good to harmonize the selected low light camera parameters and test methods with camera analysis models [51-54, 82] in order to provide that the modelled parameters could be measured too.

Low light level camera calibration and spectral sensitivity measurements [83] are very important part of the camera testing metrological support.

The efforts made to unify the measurement methods in order to use them for different type of low light level camera measurements are considered important nowadays and it will be continued in the future.

Measurement methods simplification is a new trend gaining more interest especially in the consumer camera production testing. The main goal is to make them applicable for reliable routine testing in the camera production or routine testing for predefined purpose [84]. The experience from one of the measurement set-up and related methodology for advanced imager performances [85] developed for IR systems could be used to define low light level imaging systems evaluation.

All attempts related to the development of the objective measurement methods [86, 87] should be reconsidered in case of the low light level imaging systems.

Some parameter redefinition and measurement methods adaptations to be more related to the field conditions will be a task that dominates in the future low light camera evaluation methods research.

The attempts to make better connection of the lowlight level camera testing methods with general image quality definition and assessment methods, will be interesting area of new developments.

The studies regarding potential measurement errors and uncertainty are important part of the measurement methodology development and standardization [88].

Some specific measurement methods connected with evaluation of the new technologies or to specific applications will be developed in the future but it is expected that they would be only modification of the existing ones.

Conclusions

New developments in high-resolution digital imaging sensors testing will be based on advanced versions of existing testing methodologies or even development of the new ones. Performance improvements should be expected in the area of application of the SWIR sensors connected with low light imaging and also active illumination laser supported gated imaging.

To increase the spatial resolution of imaging sensors, manufacturers typically decrease pixel size. When chip size is constant, this creates a tradeoff between resolution and dynamic range. The application of the advanced de-blurring preprocessing algorithms will provide that small pixel will be a more often solution.

Natural images may then exceed the dynamic range of the sensor, resulting in saturated pixels. Reducing the dynamic range of a sensor will produce unwanted spatial noise in the dark regions of the rendered image that will require novel approach in the image processing and imager testing methods.

Technology opens new opportunities, different camera geometry and (absolute) multispectral capabilities that will require novel testing methods. The current experience might help to design new testing environment.

Image quality and quality of derived products are important for the customers, and imager testing methodology will become more important part in the whole imager quality control chain.

Digital systems make new applications possible (and necessary), because of a new kind of information, new products and data fusion with products from other data sources. The real challenge will be testing of the fused imagers.

New products are possible providing a wide range of new data from radiometric calibrated data to automatic target recognition and tracking.

Radiometric calibration in the lab is a challenging task requiring significant role of the metrological support.

Digital camera systems have the potential to substitute film cameras and have the ability to generate new products for consumers market that will require novel approach to testing of the camera system and particularly low light level camera capabilities.

Recent developments of the low-level camera testing methods provide good and applicable results but additional efforts are necessary in the area of standardization and new methods developing that will support improved performances and wider application.

The review of the new low light level (LLL) technologies developments shows that these devices have improved performances and significant applications. Because of that, the new or improved testing methods are necessary, together with improved metrological support and more extensive standardization efforts. The review of the currently existing testing methods shows that current testing methods are good basis, but additional efforts are necessary to improve testing methodology standardization and better metrological support in case of low light level devices testing and application.

References

[1] CHRZANOVSKI,K.: *Review of night vision technology*, Opto−Electron. 2013, Rev., 21, No.2.

[2] PERIĆ,D., LIVADA,B.: *Night Vision Technology Breakthroughs*, 9th International Conference on Defensive Technologies, OTEH 2020, Belgrade, Serbia, 15-16 October 2020.

[3] HOLST,G.C.: *Testing and Evaluation of Infrared Imaging Systems*, 2nd Ed.; JCD Publishing: Winter Park (FL), USA, 1998.

[4] BIJL,P., TOET,A., VALETON,J.M.: *Electro-Optical Imaging System Performance Measurement*, in Encyclopedia of Optical Engineering, , pp. 443-450, Marcel Dekker, Inc, New York, USA, 2003

[5] BIJL,P., VALETON,J.M., HOGERVORST,M.A.: *A critical evaluation of test patterns for EO system performance characterization*, Proc. SPIE, 2001., vol.4372, pp.27–38.

[6] CHRZANOWSKI,K.: *Present status of metrology of electro-optical surveillance systems*, Proc. SPIE 10433, p 104330W, October 2017

[7] LIVADA,B., BABIĆ,V.: *Noćne optoelektronske sprave sa pojačavačima slike*, Vojnotehnički glasnik, 1992., No.1, str.18-35.

[8] LIVADA,B., PERIĆ,D.: *Imaging Detector Technology: A short Insight in history and Future possibilities*, 7th International Scientific Conference OTEH 2016, Belgrade, 06-07 October 2016

[9] PERIĆ,D., LIVADA,B.: *Technical, Technological and Application Limitations of the Electro-optical Surveillance Systems*, 8th International Scientific Conference OTEH 2018, Belgrade, 11-12 October 2018,

[10] LIVADA,B.: *Radiometrija i fotometrija: Definicije, oznake, jedinice, konverzioni faktori*, Naučno-tehnički pregled (Scientific Technical Review), 1985., vol.35, No.1, pp.38-49.

[11] National Research Council, Seeing Photons: Progress and Limits of Visible and Infrared Sensor Arrays. Washington, DC: The National Academies Press, 2010.

[12] MISHRI,L., VATSIA,U., STICH,K., DUNLAP,D.: *Night Sky Radiant Stearance from 450 to 2000 nanometers*, US Army NVL R&D Technical Report ECON-7022, NTIS AD-750 609, September 1972

[13] RICHARD,H.V., MAURER T.: *Night illumination in the visible*, NIR, and SWIR spectral bands, Proc. SPIE 5076, pp. 60-69, 2003

[14] RICHARD,H.V., DRIGGERS,R.G., HODGKIN,VAN A.: *Night illumination in the near- and short-wave infrared spectral bands and the potential for silicon and indiumgallium-arsenide imagers to perform night targeting*, Optical Engineering 52(4), p 043202, 2013

[15] HÜBNER,M., ACHTNER,B., KRAUS,M., SIEMENS,C., MÜNZBERG,M.: *Verification of sensitivity enhancement of SWIR imager technology in advanced multispectral SWIR/VIS zoom cameras with constant and variable F-number*, Proc. SPIE 9819, p 981905, 2016

[16] RICHARDS,A., HÜBNER,M.: *A new radiometric unit of measure to characterize SWIR illumination*, Proc. SPIE 10178, p 101780C, 2017

[17] HÜBNER,M., RICHARDS,A.: *Outline for a radiometric unit of measure to characterize SWIR illumination*, SMSI 2020 Conference – Sensor and Measurement Science International, Nuremberg, Germany, 2020

[18] RICHARDS,A.: *Measurements of SWIR backgrounds using the swux unit of measure*, Proc. SPIE vol. 10625, p 106250P, 2018

[19] Ohta,J.: *Smart CMOS Image Sensors and Applications*, CRC Press, Taylor & Francis Group, LLC, Boca Raton, 2020

[20] Udo Schuhle, Intensified solid state sensor cameras: ICCD and IAPS, ch 25, in Observing Photons in space - A Guide to experimantal Space Astronomy, Springer Verlag, New York, 2013

[21] LIU,X.CHIAO), BOYD,A., FOWLER,S.K., VU,O.P., WEN,D.D., DO,H., HORNA,S.: *CCD / CMOS Hybrid FPA for Low Light Level Imaging*, Proc. of SPIE, 2005., vol.5881, p.58810C-1.

[22] BIGAS,M., CABRUJA,E., FOREST,J., SALVI,J.: *Review of CMOS image sensors*, Microelectronics Journal 37, 2006., pp.433–451,

[23] FEREYRE,P., DEVRIÈRE,F., GESSET,S., GUILLON,M., LIGOZAT,T., MAYER,F., POWELL,G., PREVOST,V., RAMUS,F., SEIGNOL,O.: *L^2CMOS Image Sensor for Low Light Vision*, 2011 International image sensor workshop -Onuma Prince Hotel 2011, June 8-1,1 Hokkaido, Japan

[24] JERRAM,P., POOL,P.J., BELL,R., BURT,D.J., BOWRING,S., SPENCER,S., HAZELWOOD,M., MOODY,I., CATLETT,N., HEYES,P.S.: *The LLCCD: low-light imaging without the need for an intensifier*, Proc. SPIE 2001., vol.4306.

[25] FOWLER,B., LIU,C., MIMS,S., BALICKI,J., LI,W., DO,H., VU,P.: *Low-light-level CMOS image sensor for digitally fused night vision systems*, Proceedings of SPIE 2009., vol. 7298.

[26] MOOMAW,B.: *Camera Technologies for Low Light Imaging: Overview and Relative Advantages*, Ch.11 in "Digital Microscopy" (Editors: Greenfield Sluder David Wolf) - Methods in Cell Biology, 2013., vol. 114, pp. 243-83.

[27] HAIN,R., KA¨HLER,C.J., Tropea,C.: *Comparison of CCD, CMOS and intensified cameras*, Exp Fluids 42, 2007., pp.403–411.

[28] DRIGGERS,R.G., HODGKIN,V., VOLLMERHAUSEN,R.: *What good is SWIR? Passive day comparison of VIS, NIR, and SWIR*, Proc.

SPIE 8706, p 87060L, 2013

[29] HANSEN,M.P., MALCHOW,D.S.: *Overview of SWIR detectors, cameras, and applications*, Proc. 2008., SPIE 6939, pp. 69390I.

[30] PERIĆ,D., LIVADA,B.: *Analysis of SWIR Imagers Application in Electro-Optical Systems*, IcETRAN 2017, Kladovo, Serbia, 5-8 June, 2017.

[31] BÜCHTEMANN,W., BRÜCKNER,S., HÜBNER,M., KAMPFL,H.: *Advanced test station for imaging EO systems in the VIS to SWIR range*, Proc. SPIE vol. 10795, pp. 107950Q, 2018

[32] BIJL,P., VALETON,J.M.: *Triangle orientation discrimination: the alternative to minimum resolvable temperature difference and minimum resolvable contrast*, Opt. Eng. 37(7), pp. 1976–1983, 1998

[33] LAURENT,N., BIJL,P., DELTEL,G.: *Performance characterization of night vision equipment based on the triangle orientation discrimination methodology,* Optical Engineering 54(2), p 023104-1, 2015

[34] WATSON,A.B., FIELD,M.: *Up Periscope! Designing a new perceptual metric for imaging system performance*, Conference Proceedings Image Quality and System Performance XIII; San Francisco, CA; USA, February 15, 2016 - February 18, 2016

[35] Measurement of the minimum resolvable contrast (MRC) for image intensifier systems,- STANAG 4351, 1987

[36] Photography — Electronic still picture imaging — Resolution and spatial frequency responses - ISO 12233:2017(E), 2017

[37] Standard for Characterization of Image Sensors and Cameras, EMVA Standard 1288, Release 3.0, European Machine Vision Association, November 29, 2010

[38] Consumer Camcorder or Video Camera Low Light Performance - ANSI/CEA-639, ANSI/CEA, 2010

[39] FARRELL,J., XIAO, F., KAVUSI,S.: *Resolution and light sensitivity tradeoff with pixel size*, Proc. SPIE vol. 6069, p 60690N, 2006

[40] WANG,Z., BOVIK,A.C., LIGANG,L.: *Why is image quality assesment so difficult?*, 2002 IEEE International Conference on Acoustics, Speech, and Signal Processing, Orlando, 13-17 May 2002

[41] KOCIĆ,J., POPADIĆ,I., LIVADA,B.: *Image Quality Parameters: A short review and applicability analysis*, 7th International Scientific Conference OTEH 2016, Belgrade, 06-07 October 2016

[42] OUNI,S., CHAMBAH,M., HERBIN,M., ZAGROUBA,E.: *Are Existing Procedures Enough? Image and Video Quality Assessment: Review of Subjective and Objective Metrics*, Proc. SPIE Vol. 6808, p 68080Q, 2008

[43] MOHAMMADI,P., EBRAHIMI-MOGHADAM,A., SHIRANI,S.: *Subjective and Objective Quality Assessment of Image: A Survey*, Majlesi Journal of Electrical Engineering, 9(1), 55-83, 2014, Retrieved from http://mjee.iaumajlesi.ac.ir/index/index.php/ee/article/view/1376 (14.07.2021.)

[44] LEACHTENAUER,J.C.. MALILA,W., IRVINE,J., COLBURN,L., SALVAGGIO,N.: *General Image-Quality Equation: GIQE*, Applied Optics, Vol. 36, No. 32 pp. 8322-8329, 1997

[45] THURMAN,S.T., FIENUP,J.R.: *Analysis of the general image quality equation*, Proc. of SPIE Vol. 6978, p 69780F-1, 2008

[46] HINDSLEY,R., RICKARD,L.: *The General Image Quality Equation and the structure of the modulation transfer function*, Proc. of SPIE, Vol. 5491, p 1557, 2004

[47] COTA,S.A., FLORIO,C.J., DUVALL,D.J., LEON,M.A.: *The Use of the General Image Quality Equation in the Design and Evaluation of Imaging Systems*, Proc. of SPIE, Vol. 7458, p74580H-1, 2009.

[48] HAEFNER,D.P., FANNING,J.D., TEANEY,B.P., BURKS,S.D.: *Color Camera Measurement and Modeling for Use in the Night Vision Integrated Performance Model (NV-IPM)*, Proc. of SPIE, Vol. 9071, p 90710I, 2014

[49] KEßLER,S., GAL,R., WITTENSTEIN,W.: TRM4: *Range performance model for electro-optical imaging systems*, Proc. SPIE vol.10178, p.101780P, 2017

[50] REZAGHOLIZADEH,M., CLARK,J.J.: *Image Sensor Modeling: Color Measurement at Low Light Levels*, J. Imaging Sci. Technol., 58(3): pp. 000000-1_000000-11, 2014

[51] FELTZ,J.C.: *Development of the modulation transfer function and contrast transfer function for discrete systems, particularly charge coupled devices*, Opt. Eng. Vol. 29, No. 8, pp. 893-904, 1990

[52] FOWLER,B., LIU,X.(CHIAO).: *Analysis and Simulation of Low Light Level Image Sensors*, Proc. of SPIE, Vol.6201, p 620124, (2006)

[53] TEANEY,B., REYNOLDS,J.: *Next generation imager performance model*, Proc. SPIE 7662, p 76620F, 2010

[54] GOSS,T.M., FOURIEA,H., VILJOENA,J.W.: *SWIR sensor "see-spot" modelling and analysis*, Proc. SPIE, Vol. 11001, p 1100105, 2019

[55] BÜCHTEMANN,W., BRÜCKNER,S., HÜBNER,M., KAMPFL,H.: *Advanced test station for imaging EO systems in the VIS to SWIR range*, Proc. SPIE, 10795, p 107950Q, 2018

[56] GERKEN,M., SCHLEMMER,H., HAAN,H.A., SIEMENS,C., MÜNZBERG,M.: *Characterization of SWIR cameras by MRC measurements*, Proc. SPIE 9071, p 907110, 2014

[57] STANAG 4349 - Measurement of the minimum resolvable temperature difference (MRTD) of thermal cameras, NATO, 1995

[58] PERIĆ,D., LIVADA,B.: *MRTD measurements role in thermal imager quality assessment*, IcETRAN 2019, Srebrno Jezero 3-6 June 2019

[59] LIVADA,B.: *Minimalna razloživa temperaturska razlika (MRT): Osnovni parametar kvaliteta termovizijskih uređaja*, (1999) XLIII Jugoslovenska Konferencija ETRAN 99, Zlatibor 20-22 September 1999

[60] LIVADA,B.: *Karakteristike termovizijskih uređaja*, Naucno Tehnicki Pregled (Scientific technical Review), Vol.XLVIII, No4, pp. 86-94, 1998

[61] STANAG 4347 - Definition of static range performance for thermal imaging systems, NATO, 1995

[62] WITTENSTEIN,W.: *Minimum temperature difference perceived – a new approach to assess undersampled thermal imagers*, Optical Engineering 38(5), pp. 773–781, 1999.

[63] LAURENT,N., BIJL,P., DELTEL,G.: *Performance characterization of night vision equipment based on the triangle orientation discrimination methodology*, Optical Engineering 54(2), 023104, 2015

[64] FARRELL,J., XIAO,F., KAVUSI,S.: *Resolution and light sensitivity trade off with pixel size,* Proc. SPIE 6069, p 60690N, 2006

[65] DEN DEKKER,A.J., VAN DEN BOS,A.: *Resolution: a survey*, J. Opt. Soc. Am. A , Vol. 14, No. 3, pp. 547-557, 1997

[66] GIJS,J., VERMEER,O.: *Factors affecting spatial resolution*, Geophysics, vol. 64, No. 3, pp. 942–953, 1999

[67] OpenStax, "Limits of Resolution: The Rayleigh Criterion", downloaded 17.07.2021, https://opentextbc.ca/openstaxcollegephysics/chapter/limits-of-resolution-the-rayleigh-criterion/

[68] LOEBICH,C., WUELLER,D., KLINGEN,B., JAEGER,A.: *Digital camera resolution measurements using sinusoidal Siemens stars*, Proc. SPIE vol. 6502, p 65020N, 2007

[69] ESTRERA,J.P., OSTROMEK,T., BACARELLA,A., WAYNE,I., IOSUE,M.J., SALDANA,M., BEYSTRUM,T.: *Advanced Image Intensifier Night Vision System Technologies: Status and Summary* 2002, Proc. SPIE, vol. 4796, pp. 40-50 , 2002

[70] BHASIN,I.J., GOYAL,N.K., JAIN,V.K.: *Electrooptical Evaluation Techniques of Image Intensifier 'Ibbes - Part I*, Defence Science Journal, Vol. 54, No. 2, , pp. 199-208, 2004

[71] BHASIN,I.J., GOYAL,N.K., JAIN,V.K.: *Electrooptical Evaluation Techniques of Image Intensifier 'Ibbes - Part II*, Defence Science Journal, Vol. 54, No. 2, pp. 503-513, 2004

[72] BAKER,S.A., ROGERS,G,M., SANDERSA,F.: *Evaluating intensified camera systems*, Proceedings of SPIE, Vol. 4128, pp. 99-109, 2000

[73] PODOBEDOV,V. B., EPPELDAUER,G.P., LARASON,T.C.: *Calibration of night vision goggles: an SI-units-based gain measurement technique*, Applied Optics, Vol. 56, No. 21, p 5830, 2017

[74] "Measurement of Minimum Illumination (MMI) - The Axis Method", Axis Communication, Lund, Sweden, Technical Note, Rev: 1.0, 2006

[75] DAIGLE,O., DJAZOVSKI,O., LAURIN,D., DOYON,R., ARTIGAU,E.: *Characterization results of EMCCDs for extreme low light imaging*, Proc. SPIE 8453, p 845303, 2012

[76] PELTOKETO,V.T.: *Benchmarking of Mobile Phone Cameras*, Acta Wasaensia, 352, University of Vaasa, Finland, 2016

[77] WILLIAMS,D., BURNS,P.D.: *Applying and Extending ISO/TC42 Digital Camera Resolution Standards to Mobile Imaging Products*, Proc. SPIE Vol. 6494, p 64940H, 2007

[78] WUELLER,D.: *Low Light Performance of Digital Still Cameras*, Proc. SPIE 8667, 2013

[79] ERREA,S., GRIGOR,J., KING,D.F., MATIS,G., MCHUGH,S., MCKECHNIE J., NEHRING,B.: *Advanced E-O Test Capability for U.S. Army Next-Generation Automatic Test System*, Proc. of SPIE 2015, Vol. 9452, p945205.

[80] WONG,P.W., LU,Y.H.: *A method for the evaluation of wide dynamic range cameras*, Proc. of SPIE, 2012, vol. 8299.

[81] RICHARDS,A., DURELL,C., JABLONSKI,J., HÜBNER,M.: *SWIR Camera Test – The New Swux Unit*, White paper, Labsphere,

downloaded 16.07.2021, - https://www.labsphere.com/support/system-product-brochures/white-paper-swir-camera-test-the-new-swux-unit/

[82] XU,P., HUANG,C., HAO,Q., WANG,Y.: *Studying contrast transfer function of remote sensor with physical simulation system*, Optics and Lasers in Engineering 43, 2005., pp.1151–1158,

[83] BURGGRAAFF,O., SCHMIDT,N., ZAMORANO,J., PAULY,K., PASCUAL,S., TAPIA,C., SPYRAKOS, E., SNIK,F.: *Standardized spectral and radiometric calibration of consumer cameras*, Optics Express 2019., Vol.27, Issue 14, pp.19075-19101.

[84] MURPHY,E.: *A Review of Standards Defining Testing Procedures for Characterizing the Color and Spatial Quality of Digital Cameras Used to Image Cultural Heritage*, Technical Report, Munsell Color Science Laboratory Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, March 15, 2004, Downloadable; http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.298.4459

[85] SOEL,M.A., IRWIN,A., GAULTNEY,P., WHITE,S.G., MCHUGH,S.W.: *High-End Infrared Imaging Sensor Evaluation System*, Proc. SPIE Vol. 4719, pp. 172-188, 2002

[86] AMON,F.K., LEBER,D., PAULTER,N.: *Objective Evaluation of Imager Performance*, Fifth International Conference on Sensing Technology (ICST), IEEE, 2011

[87] LETTINGTON,A.H.D., DUNN,A.M., FANG,FAIRHURST&Y.: *Proposed performance measures for imaging systems with discrete detector arrays*, Journal of Modern Optics, 2001, 48:1, pp.115-123.

[88] PONCELET,M., WITZ,J.F., PRON,H., WATTRISSE,B.: *A study of IRFPA camera measurement errors: radiometric artefacts*, Quantitative InfraRed Thermography Journal, Taylor and Francis, 2011, 8 (2), pp.165-186.

Received: 21.10.2021.
Accepted: 15.12.2021.

Provere kvaliteta digitalnih kamera za nizak nivo osvetljenosti

Rezultati razvoja senzora slike tokom poslednje četiri dekade, omogućavaju poboljšanje mogućnosti kamera u dnevnim kao i u noćnim uslovima snimanja. Zahvaljujući poboljšanim performansama kamera danas postoji vrlo široka primena senzora slike u različitim oblastima kao što su: mašinska vizija, primene kamera u prenosnim uređajima, automatizacija vožnje, primene u konceptu pametnih gradova i primene u naučnim istraživanjima. Osetljivost kamera pri niskim nivoima osvetljenosti podržava mogućnost primene i u noćnim uslovima što vodi ka masovnoj primeni kamera u sistemima obezbeđenja i sigurnosti. Nove primene zahtevaju i novi pristup definisanju parametara kvaliteta kamera i razvoju odgovarajućih mernih metoda. Kratak pregled novih dostignuća u razvoju tehnologija primenljivih u kamerama za nizak nivo osvetljenosti je prikazan kao ilustracija potrebe razvoja pogodne metrološke podrške. Pregled najvažnijih parametera kamera za niski nivo osvetljenosti kao i odgovarajućih metoda testiranja naglašava potrebu razvoja novih procedura testiranja.

Ključne reči: **kamere za nizak nivo osvetljenosti, noćno osmatranje, parametri kvaliteta kamera, procedure testiranja kamera, funkcija prenosa kontrasta, osetljivost kamera, rezolucija kamera.**