Implementing and Using the EMVA1288 Standard

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ABSTRACT

The European Machine Vision Association took in the last years the initiative of developing a measurement and reporting standard for industrial image sensors and cameras called EMVA1288.

Aphesa offers camera and sensors measurement services and test equipment according to this EMVA1288 standard. We have measured cameras of various kinds on our self-made test-equipment. This implementation and all the measurement sets require to go in the details of the standard and also show us how good it can be but also how difficult it can be.

The purpose of this paper is to give feedback on the standard, based on our experience of implementers and users. We will see that some measurements are easily reproducible and can easily be implemented while others require more research on hardware, software and procedures and also that the results can sometimes have very little meaning.

Our conclusion will be that the EMVA1288 standard is good and well suited for the measurement and characterization of image sensors and cameras for image processing applications but that it is hard for a newcomer to understand the produced data and properly use a test equipment. Developing a complete and compliant test equipment is also a difficult task.

Keywords: EMVA1288, measurement, test, characterization, experience, implementation.

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1. INTRODUCTION

The EMVA (European Machine Vision Association) took in the last years the initiative of developing a measurement and reporting standard for industrial image sensors and cameras called EMVA1288. It is also applicable to medical, security, space and other markets. This standard is now approved by JIIA and AIA as a Japanese and an American standard which gives it a global acceptance.

The EMVA1288 working group is made of sensor manufacturers, industrial camera manufacturers, system integrators, distributors, test equipment manufacturers and universities to cover the needs of all the players of the machine vision market. The following companies, in alphabetical order, are among the most active contributors to the standard: Awaiba, Aphesa, Basler Vision Technologies, Dalsa, e2v semiconductors, Image Engineering, JAI, Matrox imaging, PCO, Stemmer Imaging, TVI Vision and the University of Heidelberg (HCI). Many others companies and organizations contribute to its development.

The standard is free to download[1] and has constant improvements.

Aphesa is an image sensor consulting company offering custom camera design, HDR (High Dynamic Range) imaging consulting, development of sensor evaluation kits, camera and sensor measurement services and test equipment. The test equipment and the measurement service are used by suppliers to complete their datasheets with EMVA1288 data or for end customers to easily benchmark several suppliers. We have therefore developed our own test equipment according to the latest version of the EMVA1288 standard and it allowed us to measure many cameras of various kinds. This implementation and all the measurement sets require to go in the details of the standard and also show us how good it can be and also how difficult it can be.

The purpose of this paper is to give feedback on the standard based on our experience of implementers and users. We will see that some measurements are easily reproducible and can easily be implemented while others require more research on hardware, software and procedures; the results can sometimes have very little meaning. For example the

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quantum efficiency, the responsivity, the SNR curve (Signal-to-Noise ratio) and the overall gain are very good parameters extracted from powerful measurement methods while the DSNU and the PRNU are rather difficult to reproduce and understand. Some parameters like the non-whiteness coefficient have very little meaning. The dark current doubling temperature and the detailed spectral response curve are almost never measured due to the lack of available equipment. We will also see that some measurements are more critical than others.

There have been multiple publications in the past to promote the standard, including publications from Aphesa and other members or non-members of the working group and a few publications against the standard from non-members. We will see that arguments in favor and against the standard are both valid and that the standard is definitely good but still need further improvement in order to reach a larger market acceptance.

2. THE EMVA1288 STANDARD

The standard is applicable to line scan and area scan sensors and cameras, color and monochrome cameras, sensors and complete cameras, CCD and CMOS technologies but the cameras must have a linear response to light intensity. Further releases of the standard will include more modules to cover a wider range of camera and sensor types.

The philosophy of the standard is to develop a mathematical model of each element of a sensor or camera and to find a suitable test to extract the values for all the parameters of the model. The models and tests are developed in such a way that there is no ambiguity in device comparison and that only very little degrees of freedom are left to the manufacturer or the operator. All models are based on physical quantities expressed in standard international units. For the standard to work, all elements must be linear and all noise sources must be white and stationary.

In order to increase confidence in the standard, several members of the working group have measured the same cameras to confirm the reproducibility and repeatability of the measurement methods. The measurement setups implemented by the members of the working group are sufficiently different to prove the strength of the mathematic models and measurement principles behind the standard.

Figure 1. Only the EMVA1288 compliant data sheets and test equipments will use this logo.

More information about the standard can be downloaded from www.standard1288.org.

2.1 Mathematical model and core module

Based on a simple mathematical model of the pixel, the standard develops simple formulas that link together all the sensor parameters.

The sensor or camera parameters can then be evaluated using three simple formulas: linear signal model, photon shot noise and signal to noise ratio.

Linear signal model

$$\mu_y = \mu_{y,dark} + K\eta \frac{\lambda A}{hc} E t_{\exp}$$

where μ_y is the average of the image expressed in digital numbers, K is the overall system gain in units of electrons per digital number, η is the quantum efficiency, λ is the wavelength, A is the pixel area, h is Plank's constant, c is the speed of light, E is the irradiance in watts per square meter and $t_{\exp}$ is the exposure time.

The photoresponse plot of μ_y versus $E t_{\exp}$ is a line with a slope of $K\eta \frac{\lambda A}{hc}$ and an offset of $\mu_{y,dark}$. It represents the sensor output versus the optical input. The linear fit is limited to the unsaturated part of the curve. Saturation is defined in EMVA1288 as the point corresponding to the largest variance. When the variance starts to decrease, even if the image mean has not yet reached its maximum, some pixels start to saturate so that the distribution of the pixels is no longer gaussian.

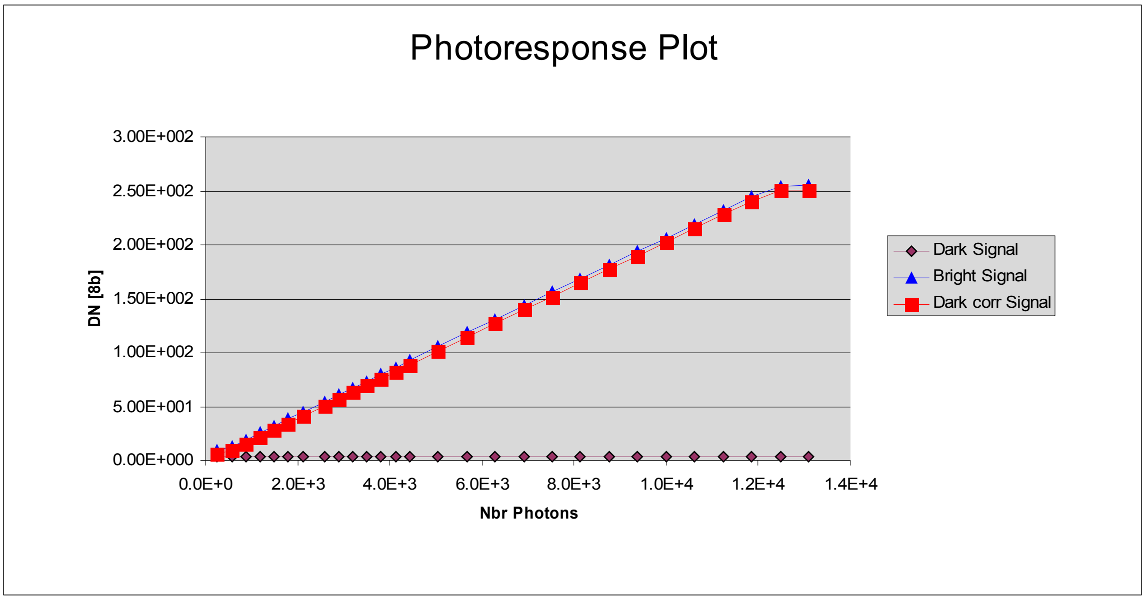

Figure 2. Photoresponse plot of an 8 bits camera (the vertical axis is the digital output between 0 and 255).

Photon transfer method

$$\sigma_y^2 = K^2 \sigma_d^2 + \sigma_q^2 + K(\mu_y - \mu_{y,dark})$$

where σ_y^2 is the image variance in DN, σ_d^2 is the variance of the dark image in electrons squared, σ_q^2 is the quantization noise and $\mu_y - \mu_{y,dark}$ is the sensor's output in DNs and corrected for its dark level. For the non-saturated part of the sensor's response, the photon transfer curve, is a line with a slope of K and an offset of $K^2 \sigma_d^2 + \sigma_q^2$.

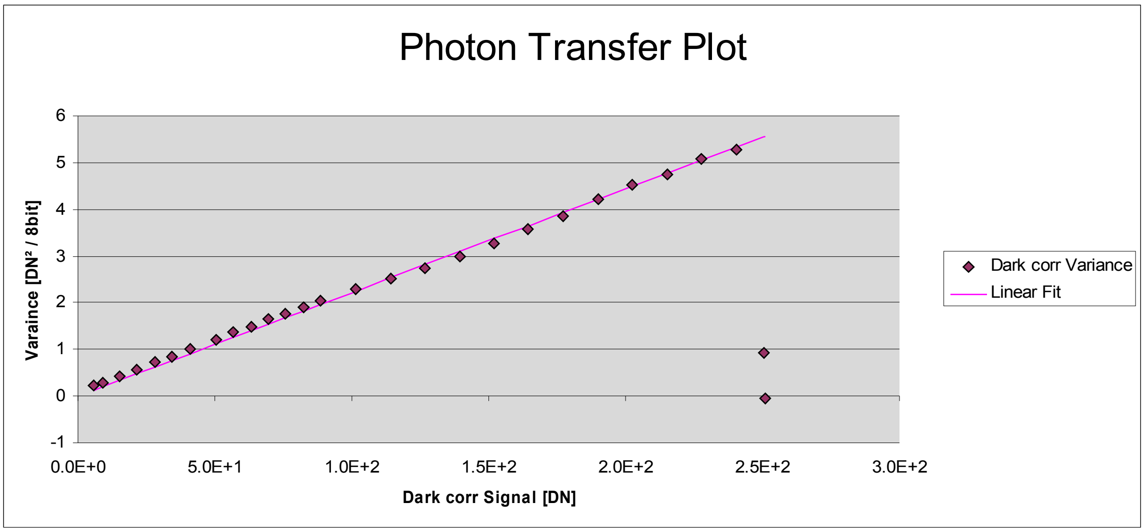

Figure 3. Photon transfer plot.

These formula show that the most important sensor parameters can be extracted from the offset and slope of a linear fit through some specific plots of the measured data. Working with a linear fit is robust against measurement errors if enough measurement points are used.

Signal to noise ratio

$$SNR(\mu_p) = \frac{\eta \mu_p}{\sqrt{\sigma_d^2 + \frac{\sigma_q^2}{K^2} + \eta \mu_p}}$$

where μ_p is the sensor's output expressed in photons. The signal-to-noise ratio is one of the most important values for an imaging system.

On a logarithmic plot of the SNR versus the irradiance, several important sensor parameters can be measured. Figure 4 shows a simplified sensor curve (plotted in bold) that has three segments.

The first segment of the SNR curve is dominated by the dark noise and the slope is 1. The lowest point of this segment is the lowest detectable light level, i.e. the sensor's sensitivity.

The second part of the curve has a slope of ½ and corresponds to the shot noise limited part of the response. This segment is parallel to the ideal SNR curve representing the shot noise of the light itself. The horizontal distance between these two segments is $\log_2 \eta$.

The last segment is horizontal and corresponds to the pixel gain noise limited part of the response (PRNU). This segment ends at the device saturation point where the variance of the image is maximum.

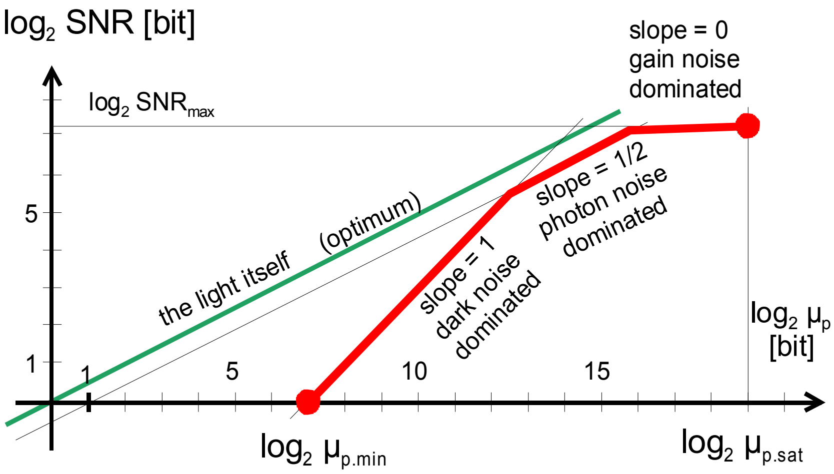

Figure 4. Signal-to-noise ratio. Reproduced from [2].

2.2 Other modules

Beside these three easy formulas, the working group also investigated other important parameters like DSNU, PRNU, dark current, dark current doubling temperature, linearity, defect pixels, spectral response and triggering. More modules will be added in the future. All modules follow the same approach: defining a model, describing a simple measurement, plotting the results against the model and finally extract the values of the modeled parameters.

2.3 Measurement setup

One of the important goals of the standard is to define the measurement setup so that many aspects of its implementation are left to the end user, this makes the basic measurement setup affordable. The light source must be diffused, disk-shaped and monochromatic (i.e. with a spectral spread of not more than 50nm).

The only requirement is that the sensor should be irradiated uniformly without a mounted lens. The sensor should see the light source under an F-number of 8. That means that the focal plane should be located at a distance from the source equal to eight times the diameter of the source.

The exposure can be varied by linearly changing the power of the light source or changing the exposure time of the sensor.

3. DIFFICULTIES TO IMPLEMENT AND USE THE STANDARD

3.1 Hardware difficulties

The EMVA1288 standard specifies the minimum uniformity and minimum monochromaticity of the illumination. Reaching the minimum FWHM (Full Width Half Maximum) of 50nm is not difficult as this is easily reached with optical bandpass filters for the systems that use wide spectrum illumination; for the systems that use LEDs, most LEDs are within the 50nm upper limit. In order to work with multiple LEDs (to reach higher uniformity and light intensity), it is required to measure and sort the LEDs in order to guarantee the best possible spectrum.

The biggest difficulty is to reach sufficient uniformity over the illuminated area. There are two kinds of uniformities of concern: slow spatial variations of light intensity over a large area and fast spatial variations of light intensity.

The slow spatial variations must be limited in their maximum amplitude and they define the maximum sensor diagonal that can be measured on the test equipment. The intensity is usually less on the periphery of the illuminated area than in its center and it drops faster and faster as the distance from the center is increased. It is hard to design a system that can reach diagonals of over 2”, which is require in order to measure high resolution sensors or line scan sensors.

The fast spatial variations affect the measurement of PRNU, they are usually very limited due to the F/8 design and the nature of the light source; it is also possible to reduce their effect by measuring the sensor or camera at several positions or orientations under the light source.

It is also important to make the mechanical design in such a way that multiple types of cameras or lens mounts can be used. For every mount type, the focal plane has to remain at the right distance from the uniform light source and perpendicular to the direct light rays.

On the side of electronics, the control of the light source in order to reach a stable, uniform, linear, temperature compensated light source over a wide range of illumination intensity requires a lot of development and combination of technologies. Optical and electrical calibration is also necessary.

3.2 Software difficulties

There are two main difficulties in the software. One is to be able to control and acquire data from various types of cameras, the other is to implement the calculations and reporting formats specified in the EMVA1288 standard.

Interfacing cameras

There are many different camera interface standards and some cameras even do not follow any standard. Therefore, being able to measure a wide range of cameras requires significant development. A measurement system should be able to measure at least FireWire IIDC DCAM cameras, GigE-Vision cameras and CameraLink cameras up to the full interface as these three standards represent most of the commercially available industrial cameras today. There are other standards under development or already available like CoaXpress, CameraLinkHS, USB3, USB2, FireWire (non-DCAM), CameraLink 10 taps, GenTL Gen<i>cam and others that should ideally be supported.

Moreover, even though there are standards, some manufacturers implement specific features on top of standard interfaces, it is especially obvious in the CameraLink protocol where the serial communication channel with the camera is unspecified. In GigE Vision, specific camera parameters can be passed to custom register names.

Implementing the standard

The standard requires to implement many libraries of mathematical computations including linear fits, one dimensional and two-dimensional filters, maximum detection, medians, Fourier transforms, statistics, etc. Besides this, it is required to implement complex image management routines in order to efficiently run the calculations and the data accumulation in terms of speed and memory management.

When all this is implemented and stable, different implementations of the standard will still exhibit some small differences in the results that are most likely related to the selected data representation and the specific implementation of the mathematical routines. It is also suspected that the choice of compilers and operating systems also has an influence. Within the EMVA1288 working group, a sub-group is working on such specific topics in order to publish a set of recommendations and a reference implementation that can be used for benchmarking against the developper's own code. It is anyway expected that such small variations are negligible compared to the measurement errors coming from the mechanical, electronic and optical part of the system. The precision of the calibration of the reference light power detector is also expected to be lower than the precision of the calculations.

Most of the measurement methods suggested by the EMVA1288 standard are very robust against isolated measurement errors and measurement noise. Such errors can be caused by wrongly acquired images, sudden changes or noise in the light source, measurement error from the calibrated reference detector, noise of the calibrated detector or parasitic light.

However, some of the methods are more sensitive, for example the ones related to spatial noise characterization under illumination (for example the spectrograms, the PRNU and the bright non-whiteness coefficient). Their quality will depend on the light source and the size of the tested sensor.

3.3 Understanding the results

Some of the parameters measured or calculated by the EMVA1288 standard are of great importance and familiar to the imaging community; for example quantum efficiency, temporal dark noise, sensitivity, signal-to-noise ratio, linearity or dynamic range are such parameters.

The standard also makes the SNR plot mandatory. This is an important innovation in camera or sensor datasheets as SNR is truly not a value but a function of light intensity. The most important performance parameters of image sensors and cameras can be seen on the SNR plot directly.

Besides this, some other elements are difficult to understand. Although they make a lot of sense for specialists, the non-whiteness coefficients, the spectrograms and the defect pixels histograms are more difficult to understand by many end users.

Some specialist also would like to see more tests, for example row and column profiles or output noise under light over temperature.

Finally, the datasheets of two different cameras can only be compared if they are measured in the same conditions. By same conditions we mean the same illumination wavelength, the same range of exposures, the same frame rate, the same temperature and similar parameters for the other settings. It is what a measurement lab will do but because each suppliers defines his own measurement conditions, it is very likely that standard datasheets will almost never be directly comparable. This is one of the major issues for larger acceptance of the standard and the working group should define more in details a standard set of measurement conditions, if possible.

3.4 Limitations of the standard

The EMVA1288 standard is still under development and more measurements and methods will be implemented in the future. However, there are some intrinsic limitations to the standard. Such limitations include for example the fact that all pixels are exposed to the same light which makes pixel electrical crosstalk and pixel optical crosstalk impossible to measure. The standard is also not adapted to UV cameras for which two electrons can be generated for one impinging high-energy photon; it is not adapted to high-dynamic range sensors that exhibit strong non-linearities and possibly other noise structures or to any sensor that does not sufficiently follow the models used as a basis to all measurement methods.

3.5 Modules almost never used

Due to its limited interest, a parameter called the dark current doubling temperature is almost never measured and very few test equipments have the capability to measure it. This parameter is only interesting in specific applications like automotive or space. It tells the user how the camera will degrade in performance when its temperature varies.

The spectral response plot is difficult to produce with high precision. Most of the existing implementations of this module differ from the recommended implementation put forward in the standard.

4. CONCLUSIONS

The EMVA1288 standard is a very good standard well suited for the measurement and characterization of image sensors and cameras for industrial, medical, security, space and other image processing applications as it fills a gap in the list of available standards to characterize and specify the performance of system components in vision applications.

However, it is hard for a newcomer to understand the produced data and properly use a test equipment. Therefore Aphesa needs to provide a training about the EMVA1288 standard and about the test equipment for each customer at the time of delivery of an equipment. Explanations are also offered with each measurement report.

It is also difficult to implement both in hardware and in software as it requires a lot of research and a significant development time.

Detractors of the EMVA1288 standard are welcome to join the working group to help its members in the difficult task of improving the standard. Working group membership is free.

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