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CAMERA CHARACTERISATION IN EDUCATION TRAINING ACCORDING TO THE EMVA 1288 STANDARD

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Abstract – The quality of image sensors and the implementation of them into camera systems is a key fact for image processing applications. Therefore the standard EMVA 1288 was developed by the European Machine Vision Association. The paper presents an approach for teaching the basics in camera characterisation according the EMVA 1288. The goal should be to give the students a tool and experience to make the right decision for their application. Therefore a practical course was developed.

Keywords: camera characterisation, measurement of camera parameter, measurement system for camera parameters

1. INTRODUCTION

In the last decades of years a lot of different image sensors were developed by a huge variety of companies. Actually there is a strong trend to Complementary Metal Oxide Semiconductor (CMOS) based systems. These sensors are easy to integrate in customized camera electronics. Because of their high integrated on board digital signal processing as well as their analogue signal processing. Nevertheless there are a lot of options which have to be configured by the developer. Nevertheless these circuits have some critical characteristics for example the fixed noise pattern compared to Charge Coupled Device (CCD) based camera systems. As mentioned there is a second great part of image sensors these types using the CCD technology. One big advantage is the low noise level and the fixed noise pattern in contrast to CMOS -Systems. On the other side the developer of these camera systems have to take care of the right routing of the printed circuit board (PCB) and the correct timing for the read out clock generation. In both cases a lot of fine adjustments are necessary to get optimal results out of the image sensor. These facts are only a few of parameters which have to be observed. That is why one major goal of the characterisation should be, to find a way to characterise a camera layout and electronic design during the development process.

The other goal of the characterisation is application driven. Actual there is a huge of different camera systems on the market. With this method of characterisation the students should learn to find the right solution for their current imaging problem. For example if they have to solve a pick and place application the quantum efficiency has lower priority as the framerate. If they want to have a look to the fundus of the eye or want to sample special fluorescence images the focus should be on high quantum efficiency. Sure the datasheets of the image sensors will have some information of principle characteristics but the correct integration on PCB and the correct fine adjustment of parameters is the task of the developer. To compare the implementation of the complete camera system a black box model is assumed which will be characterized by variation of some significant parameters.

In the following paper a way and a test setup will be described which starts from a signal model considering the imaging chain, calculating important characteristics and close with some test data from a CMOS-based Sensor and a CCD-camera system. These apparatus will be used in the training courses according to the lecture image acquisition techniques and image system theory.

2. SIGNAL MODELL AND IMAGE PROCESSING CHAIN

Generally the task of image sensors and radiation sensors is the transformation of electromagnetic radiation into digital or analogue signals. The basic effect for this transformation is called photoelectric effect. For image sensors which are working in the UV-VIS and NIR range mainly the inner photoelectric effect is used for the transformation of light in to electrical signals.

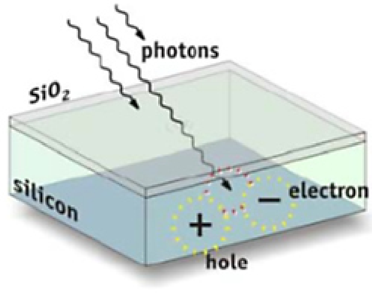

Figure 1: Generation of electron-pairs inside the semiconductor [5]

The generated photons from the radiation source hitting the sensitive material. Inside the material, mainly a semiconductor, electron-hole pairs (Figure 1) were generated in dependence of the amount of photons. This leads to an accumulation of elementary charge units e^- inside the material. These charges can be converted into voltages which are depended from the amount of photons which were collected. Inside an image sensor these active area is called pixel which can be realized as a CCD or a CMOS Element. After this elementary physical effect a lot of analogue and digital processing has to be done to get a digital value. The following Figure 2 shows the principal way inside a camera

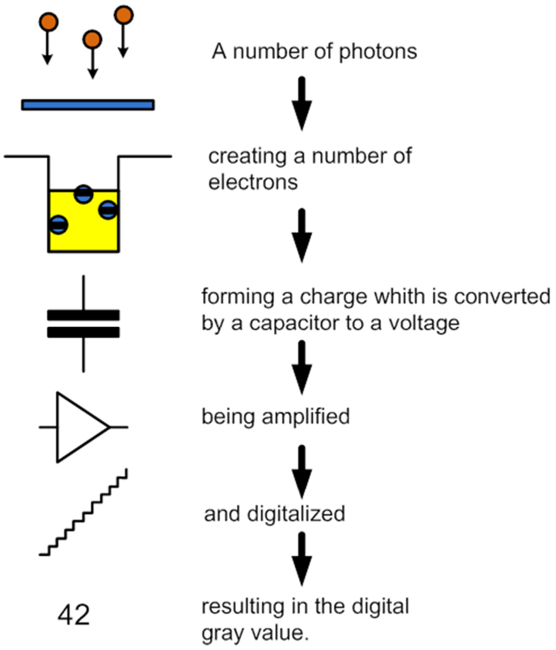

Figure 2: Model of conversion of photons in to digital values [1]

system. In consequence to the illustration the assumption for the theory behind the following steps is that the amount of photons is countable. That leads to Poisson models during the model of the transfer processes [2],[3]. According to Figure 2 and in dependence to the exposure time a special amount of photons hit to a pixel will be partly absorbed and generate a value of charge units μ_p. With the weight of the wavelength depended quantum efficiency an average value μ_e of charge units can be converted into electrical signals.

$$\eta(\lambda) \cdot \mu_p = \mu_e \qquad (1)$$

With this assumption the effects generated by the fill-factor and the influences of the microlenses mounted on the active sensor area will be included and not considered separately. The mean number of photons hitting the pixel can be calculated using the knowledge about the pixel size, exposure time and the irradiance on the sensor surface according equation (2).

$$\mu_p = \frac{AEt_{exp}}{hv} = \frac{AEt_{exp}}{h\frac{c}{\lambda}} \qquad (2)$$

With the given equations it is possible to calculate the number of photons μ_p. For that reason a precise measurement of the irradiance E on the same place where the device under test will be proofed is needed. Therefore a calibrated radiometer should be used. In accordance to the standard these devices should be recalibrated every year by the manufacturer. The camera electronics converts the radiation which is accumulated into digital values using some stages of amplification and an analog to digital conversion. This behavior can be formulated using the following equation (3) according to [1] with the introduction of the overall system gain factor K.

$$\mu_y = \mu_{y.dark} + K\mu_e \qquad (3)$$

In combination with equation (2) the mean gray value μ_y can be calculated as the sum of the mean value of the dark gray value and the product of overall system gain factor K and expected number of photons μ_e.

$$\mu_y = \mu_{y.dark} + K\eta\frac{\lambda A}{hc}Et_{exp} \qquad (4)$$

With this equation the linearity of a sensor can be calculated using the gray value of a pixel. As mentioned at the beginning the accumulation of electron hole pairs the distribution underlying an Poisson process which can be assumed as equation (5) with the variance and is known as shot noise [1, 3].

$$\sigma_e^2 = \mu_e \qquad (5)$$

With the introduction of the quantisation noise σ_q and the signal dependent normal distributed noise σ_d as well as the expected shot noise σ_e the mean noise measured in the digital signal can be written as equation (6).

$$\sigma_y^2 = \underbrace{K^2\sigma_d^2 + \sigma_q^2}_{offset} + \underbrace{K}_{slope}\left(\mu_y - \mu_{y.dark}\right) \qquad (6)$$

In combination with the radiation measurement equation (4)-(6) the noise and the overall gain factor K can be determined. Modelling the discussed major influences and system descriptions the graphical illustration is given in Figure 3.

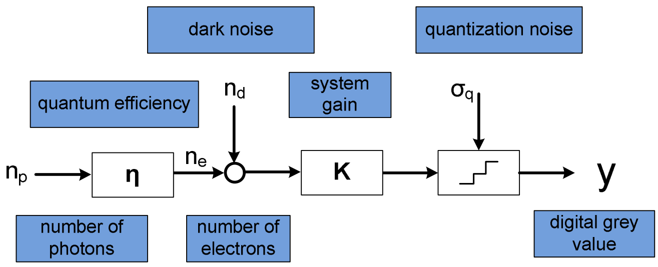

Figure 3: Graphical representation of the system model [1]

For the measurement of these parameters a special measurement setup is demanded in [1] which is developed and displayed in the chapter measurement setup. Furthermore the detailed instruction for the calculation of bad pixels dark current, sensitivity and sensor non-uniformities will be given in the section 2-4 in the standard [1].

3. MEASUREMENT SETUP

The demanded requirements for the measurements to calculate the values discussed in chapter 2 as well as in the complete standard, section 6-9 gives advices for an comparable measurement as well as the restrictions meeting the EMVA criteria. With the knowledge of that, the following Figure 4 shows the construction of the test setup.

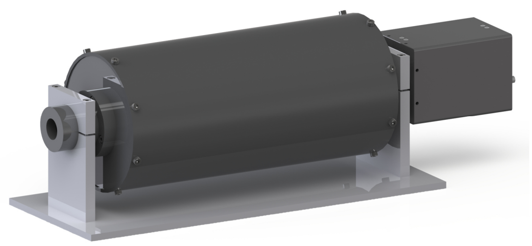

Figure 4: Test setup for measuring the different camera systems

The main criteria for the construction was the hole camera model which leads to special geometric restrictions following equation (7).

$$f_{\#} = \frac{d}{D} \tag{7}$$

With the f-number restriction of eight and with the distance d the free radiation diameter D can be calculated. One major point for this construction is the ideal wall surface behavior inside the Tube. Therefore a special painting which has an very low reflection coefficient was used. Furthermore a special camera socket was constructed for the reason of minimizing the parasitic reflections inside the mounting.

4. SOFTWARE AND STUDENTS WORK

The training software for the student training were developed using the Matlab framework. The software handles GigE-Vision cameras as well as pictures taken by the user with other systems. The complete standard was implemented in this training tool. For an evaluation of the correctness of the programmed algorithm the EMVA delivers some simulated data for the verification. This data were used to verify the system.

In the training the students firstly have to measure the irradiance which will be applied to the measurement position of the device under test. With this information they can solve a part of the equations given in chapter 2. After the measurement of the radiation power they have to adjust the camera on the setup and can start the capturing (Figure 5).

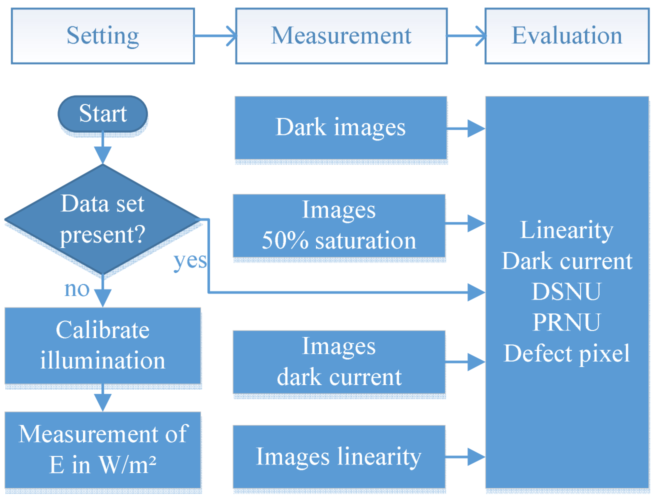

Figure 5: General procedure for data aquisition and evaluation seperated in three stages

The standard requires a special amount of pictures which will be taken automatically by the software. Inside the script the students will find some blank spaces where they have to put the correct equations into.

At the end of the camera qualification they have to generate a standard compliant datasheet of the camera they have proofed. With the plots of linearity, sensitivity and noise they have to give a oral assessment of the proofed camera system. Furthermore inside the software there is the possibility to manipulate the sensor data so that the students have the chance to vary some parameters and can look what happen into the diagrams. The following example shows the characteristic if one bit is set to zero. The effects are visible in the green marked crosses inside the Figure 6. The red crosses displaying measurements without the bit error.

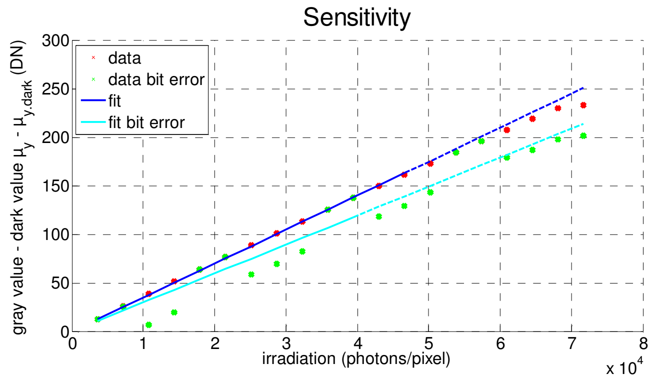

Figure 6: Example for missing codes or bad ADC characteristics

5. MEASUREMENTS

After the programming and the construction of the measurement setup first measurements were presented in short on this position. The first measurements were taken with two CCD-camera-systems with different sensors. The sensors have different pixel sizes and different quantum efficiencies. The special characteristic for this measurement is the equal set of the exposure times between the different cameras. So it the different saturation levels as well as the different sensitivity coefficients became visible very clearly (Figure 7).

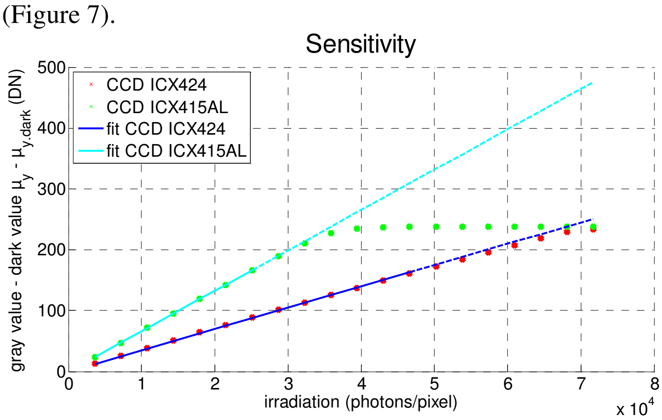

Figure 7: Sensitivity measurements with different camera systems

Furthermore the illustration gives a good understanding what the saturation point is for the camera system which is marked with the green dots.

5. CONCLUSIONS

The presented summary shows a abstract of the possibility to characterise imaging sensors using the standard EMVA 1288. With the knowledge and the discussion during this practical course the students should get a feel hoe complex such a system is and how they can get valuable information out of a system with an approach based on a system model. In the full paper more experimental data as well as some additional information about the processing will be given.

ACKNOWLEDGMENTS

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