Practical Measurement and Comparison of CCD and CMOS Image Sensors Dynamic Range

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Abstract - **This paper contains information about practical results for measure, calculation and compare dynamic range of cameras, which are made of principle different technologies for their image sensors producing – CCD and CMOS. The measurement is made upon special experimental structure and working methods, which are described below.**

Keywords – **CMOS, CCD, camera, sensor, dynamic range, statistics**

I. Introduction

Well known CCD (from Bell Labs research) and the new one CMOS sensors there will be a significant role in imaging for the foreseeable future. Both type of sensors are constructed from metal-oxide-semiconductor technology. This gives them fundamentally similar properties of sensitivity over the visible and near-IR spectrum. Thus, both imagers convert insident light (photons) into electronic charge (electrons) in each pixel by the same fotoconvertion process, serving a spatial sampling functuon.

In the regard of transfering the collecting charge the solutions are different. CCD transfers each pixel's charge packet sequentially to a common output structure which converts the charge to a voltage, buffers it and sends it off-chip. In CMOS the charge-to-voltage conversion takes place in each pixel by implemented amplifiers around sensing elements. This is known as active pixel CMOS sensor (APS). This difference in read-out has significant implications for sensor architecture, capabilities and limitation. There are many attributes characterize image sensor performance. In this paper is highlighted dynamic range. There are two ways for define the dynamic range. First is an optical dynamic range and it is calculated by :

$$DR, dB = \frac{SEE}{NEE}, \qquad (1)$$

where SEE (Saturation Equivalent Exposure) is the exposure level that produces a saturation output level and NEE (Noise Eqiuvalent Exposure) is defined as the number of Joules of light energy per unit area required to generate an output signal equal to the output noise level. This describes the lower limit on detectable light energy. The light source wavelength distribution must be specified for a definite value. Second definition is for electrical dynamic range and is expresed by :

$$DR, dB = \frac{SAT}{NOISE}, \qquad (2)$$

where SAT is the average maximum output level for a specified light input and NOISE is inherent noise of the sensor.

Hence we can define the following sequence to measure this parameter for two kind of sensors and to compare achieved values :

1. Take down a picture from sensor in full dark condition – without illumination ;
2. Take down a picture into condition of very high level of illumination, but before saturation of pixels ;
3. After obtaining results it is nesesary to make statisticalprocessing under them for a meaningfull values. It includes histogram H(X) (grayscale distribution), i.e. probability P(X), mathematical expectation E(X) and dispertion D(X) of random value X, which represents grayscale value of separate pixels. Exists the following relationchips between them :

$$H(X) = P(X) = \sum_{i=1}^{n} P_i(X) \text{ -} \qquad (3)$$

probability of X

$$E(X) = X \cdot P(X) \text{ -} \qquad (4)$$

mathematical expectation of X

$$D(X) = E(X^2) - [E(X)]^2 \text{ -} \qquad (5)$$

dispertion of X

$$\sigma = \sqrt{D(X)} \text{ -} \qquad (6)$$

average square offset

4. There was used additional equation for calculating optical power of illumination :

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$$P,[dBm] = 10\log(\frac{P_{measure},[W]}{1mW}) \qquad (7)$$

5. At the end it must be make a ratio between results of the two measurement – dark and light pictures and dynamic range is calculated :

$$DR,[dB] = 20\log(\frac{P_{light} \cdot E(X)_{light}}{P_{dark} \cdot E(X)_{dark}}) \qquad (8)$$

II INITIAL CONDITIONS FOR TESTING

For aims of the experiment there was used CCD camera TVCCD-200 from Monacor (Germany) and CMOS camera CCf15 from C-CAM Technologies (Belgium).

TVCCD-200 is based on CCD sensor with pixel resolution 500 x 580, signal-to-noise ratio > 46dB and minimal light sensivity 0,1 Lux (as described in data sheet) . Output signal is obtained as video signal. There was used frame grabber PC-Image SC from Matrix-Vision (Germany) and company software for PC connection with camera and Image Pro Plus software packet for processing results.

CCf15 is equipped with the Fuga15d cmos image sensor designed by Fillfactory. This sensor is 512 x 512 pixels addressable single chip imager with logarithmic response, which results in an extended dynamic range (6 decades light, i.e. 120 dB as described in data sheet). This means that 6 orders of magnitude of intensity can be captured in the same image. This sensor is specially designed for very high light level. There is included on-chip 8-bit flash ADC and automatic illumination control. The picture elements are three-transistors with true random access and possibility of sub sampling due to which it is possible to read out the camera at higher frame rates, as is visible from the Fig. 1.

The sensor behaves like a 256 Kbytes ROM – after applying an X-Y address (x-y position in matrix), the pixel intensity is returned in a digital word of 8 bits.

Connection with camera is established with a powerful imaging interface PCI-LVDM (Low Voltage Differential Signaling). The interface card can be used as a simple frame grabber or as an intelligent image preprocessor based on included field programmable gate array (FPGA).

Two kind of cameras are used without integration time adjustment.

For experiments was used camera supporting software (PCI.EXE), which can read pixels values and store them in a file.

Illumination measurement is made with 1 mm diameter sensitive head.

III. PRACTICAL RESULTS

Based on everything mentioned above there was established the results :

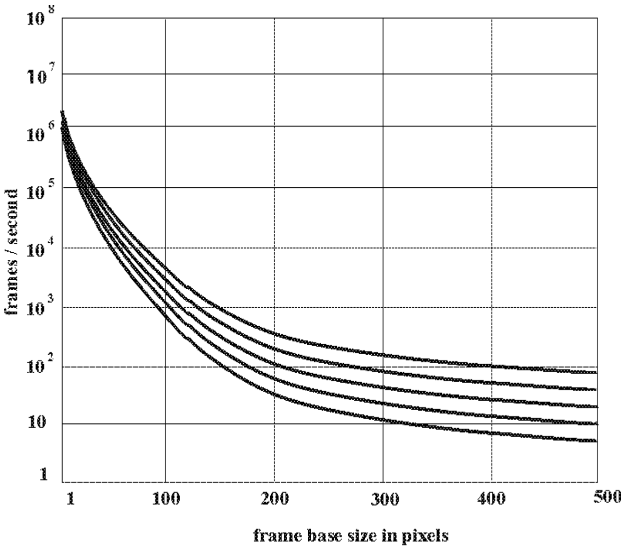

Fig. 1. Frame speed vs. resolution

1. Dark histogram for CCD (noise picture) : illumination : $-92{,}5\ dBm$ and statistical results:

$$E(X) = 27{,}38160$$
$$\sigma = 0{,}5020113$$

Hence, most probability value is $27 \pm 0{,}5$ and also histogram is shown in Fig. 2.

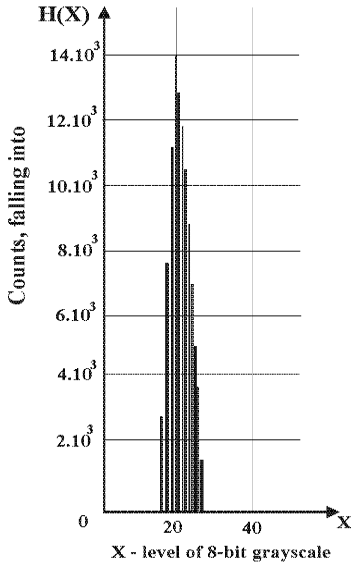

Fig. 2. Noise picture for CCD sensor

2. Light histogram picture of CCD under illumination of $-81{,}1dBm$ and statistical meanings of :

$$E(X) = 248{,}9185$$
$$\sigma = 8{,}67023$$

gives most probability value 249 ± 9 and histogram is given in the following Fig. 3. :

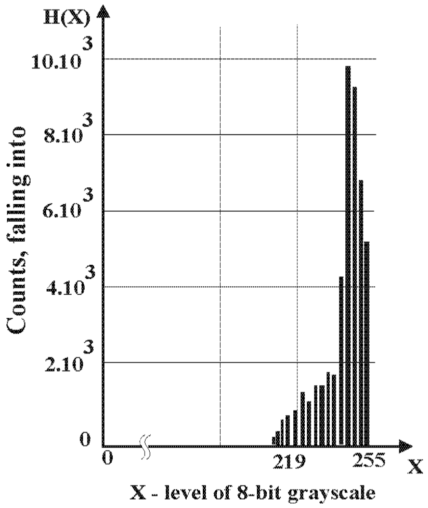

Fig. 3. Light histogram of CCD sensor

From this point we can calculate:

$$(P_{measure})_{dark} = 0{,}56\,pW$$

$$(P_{measure})_{dark} = 7{,}8\,pW$$

and dynamic range :

$$DR,[dB] = 20\log(\frac{249.7{,}8}{27.0{,}56}) = 42dB$$

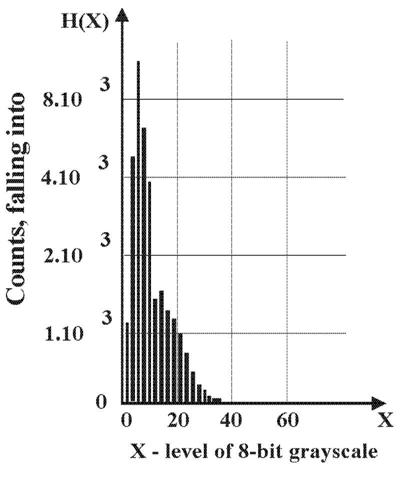

Fig. 4. Dark (noise) histogram of CMOS sensor

For the cmos camera into two condition the data is the following :

1. Dark histogram :

illumination : $-92{,}5dBm$, statistical value 10 ± 14 and histogram picture shown in Fig.4.

2. As the end step we have achieved light histogram under illumination of $-68dBm$ and statistical values 204 ± 8 and histogram picture is present on Fig. 5.

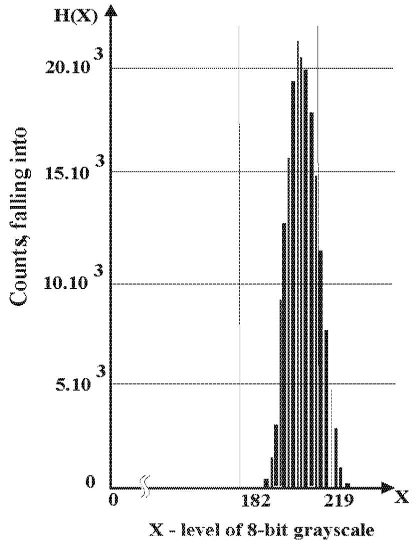

Fig. 5. Light histogram of CMOS

The results from calculations are:

$$(P_{measure})_{dark} = 0{,}56\,pW$$

$$(P_{measure})_{dark} = 158\,pW$$

$$DR,[dB] = 20\log(\frac{204.158}{10.0{,}56}) = 75dB$$

V. Conclusion

It is obviously that CMOS imager is better then CCD in view point of dynamics. But it is necessary for highlighting that both sensors – CCD and CMOS have advantages and disadvantages in the regard of different working parameters. For the moment CCD and CMOS remain complementary technologies. But the tendensy is CMOS sensors to consume more of the CCD traditional's applications.

References

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