Accurate measurement of spatial noise portraits of photosensors of digital cameras

P A Cheremkhin, N N Evtikhiev, V V Krasnov, M N Kulakov, R S Starikov
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, 115409 Moscow, Russia

E-mail: PACheremkhin@mephi.ru

Abstract. Method of measurement of accurate portraits of light and dark spatial noise of photosensors is described. The method consists of four steps: creation of spatially homogeneous illumination; shooting light and dark frames; digital processing and filtering. Unlike standard technique, this method uses iterative creation of spatially homogeneous illumination by display, compensation of photosensor dark spatial noise portrait and improved procedure of elimination of dark temporal noise. Portraits of light and dark spatial noise of photosensors of a scientific digital camera were found. Characteristics of the measured portraits were compared with values of photo response and dark signal non-uniformities of camera’s photosensor.

1. Introduction
Basic element of any digital photo- and videocamera is the photosensor [1-3]. Photosensor consist of pixels and the number of pixels in modern digital cameras is equal to tens of millions. Due to imperfections of production of photosensors, photosensitivities of separate pixels are slightly different. In result any photosensor has inherent light spatial noise portrait (LSNP) [4] and dark spatial noise portrait (DSNP). LSNP represents the array of relative differences of photo responses of separate pixels. DSNP is array of dark spatial non-uniformities of pixels.

The knowledge of LSNP and DSNP potentially allows to increase the signal-to-noise ratio of the images [5-7]. To suppress temporal and spatial noises, flat-field correction [8-10] or dark correction [8] techniques are used. We propose modification of flat-field correction technique for image signal-to-noise ratio increasing. Unlike the sky flats or twilight flats that commonly used in flat-field correction technique [9-10] we proposed to use compensation of LSNP and DSNP of camera's photosensor for spatial noise suppression [5-7]. As the proposed modification is aimed to reduce spatial noise, it is effective after application of others methods of SNR increasing that suppress temporal noise.

Other variant of application of the LSNP and DSNP is identification of digital photocameras based on a number of images [4] and identification of digital videocameras based on available video [11]. Besides identification of cameras, the LSNP is suitable for detection of existence and nature of editing contents of a picture, an assessment of age of pictures, and etc. [12-15].

In this paper we measured the LSNP of photosensor of scientific camera using the proposed modification.
2. Description of the modification of method of measurement of camera’s photosensor LSNP

Modification of method of measurement of camera’s photosensor LSNP is proposed in [5-7]. It is based on technique described in [4]. Main differences between proposed modification and presented in [4] technique are:

- iterative creation of spatially homogeneous illumination using display,
- using of compensation of photosensor dark spatial noise portrait,
- improved procedure of elimination of dark temporal noise.

Our modification consists of 4 steps:

1. Creation of a spatially homogeneous illumination of camera’s photosensor (Homogeneous distribution displayed on monitor is used for sensor illumination. On results of shooting, spatially homogeneity across sensor is analyzed, map of illumination is created and new distribution on monitor is displayed. These actives are repeated iteratively.);
2. Shooting two series of frames: with opened lid (light frames under created illumination) of and with closed lid (dark frames);
3. Digital processing of registered frames for elimination of:
   3a) dark and light temporal noise (by frames averaging)
   3b) dark spatial light (by elimination averaged dark frame from light one)
4. Digital filtering of obtained array for elimination of residual non-uniformity of illumination (by dividing on median filtered array and unity subtracting).

3. Experimental estimation of spatial noise portraits of scientific digital camera

For experimental estimation of photosensor spatial noise portraits, scientific camera MegaPlus II ES11000 was used. Its main technical characteristics are given in Table 1 [16].

Table 1. Technical characteristics of camera MegaPlus II ES11000.

| Characteristic                  | Value                        |
|--------------------------------|------------------------------|
| Sensor type                    | CCD                          |
| Quantity of pixels             | 4008 × 2672 (10.7 MP)        |
| Pixel size                     | 9μm × 9μm                    |
| Output bit depth of ADC        | Up to 12 bits                |
| Spectral                      | Monochromatic                |
| Minimum integration time       | 140μs                        |
| Maximum integration time       | > 5 s                         |

Noise and radiometric characteristics of this camera measured in [17-19] were used. They are shown in Table 2, where DN is digital numbers of signal, e-/DN is the ratio of quantity of emitted electrons in one pixel to one digital number of signal.

Table 2. Noise and radiometric characteristics of camera MegaPlus II ES11000.

| Characteristic                        | Value                   |
|---------------------------------------|-------------------------|
| Dark temporal noise                   | 2.3 ± 0.4 DN            |
| Camera gain                           | 11.88 ± 0.11 e-/DN      |
| Dark spatial non-uniformity           | 0.56 ± 0.04 DN          |
| Photo response non-uniformity         | 0.0053±0.0008           |
| Black level offset (BLO)              | 3.4 ± 0.6 DN            |
| Maximum linear signal with BLO subtracted | 3916 ± 30 DN         |
| Dark temporal noise                   | 2.3 ± 0.4 DN            |
Using the described procedure LSNP of photosensor of camera MegaPlus II ES11000 was obtained. 400 light and 400 dark frames were used. Figure 1 shows a fragment of light spatial noise portrait of MegaPlus II ES11000 photosensor. Figure 2 shows a fragment of dark spatial noise portrait of MegaPlus II ES11000 photosensor. Sizes of the fragments are 512×512 pixels.

The histogram of brightness of pixels both in DSNP and in LSNP approximately corresponds to Gaussian distribution. Mean square deviation of values of LSNP of a photosensor of the MegaPlus II ES11000 camera is equal to 0.0051. This value is average photo response non-uniformity of pixels of a photosensor of this camera. It corresponds to earlier measured value [17-19]. Mean square deviation of values of LSNP of photosensor is equal to 2.3 digital signal levels (or 26 e− using camera gain value). This value corresponds to average dark signal non-uniformity of pixels of the camera.

![Figure 1](image1.png)

**Figure 1.** A fragment of light spatial noise portrait of camera MegaPlus II ES11000 photosensor. Size is 512×512 pixels.

![Figure 2](image2.png)

**Figure 2.** A fragment of dark spatial noise portrait of camera MegaPlus II ES11000 photosensor. Size is 512×512 pixels.
4. Conclusion
Thus, experiments on measurement of portraits of light and dark spatial noises of photosensor of the scientific digital camera were performed. Characteristics of the measured portraits correspond to photo response and dark signal non-uniformities of the photosensor. The obtained portraits allow to increase the signal-to-noise ratio of the images registered by this camera.

Acknowledgments
This work was partially supported by grant 14-19-01751 from the Russian Science Foundation (RSF).

References
[1] Janesick J 2001 Scientific Charge-Coupled Devices (Bellingham-Washington: SPIE Press)
[2] Nakamura J 2006 Image sensors and signal processing for digital still cameras (Boca Raton, FL: CRC Press)
[3] Baker R J 2011 CMOS: Circuit Design, Layout, and Simulation: Third Edition (John Wiley and Sons)
[4] Fridrich J 2009 IEEE Signal Processing Magazine 26 26-37
[5] Evtikhiev N N, Starikov S N, Cheryomkhin P A, Krasnov V V and Rodin V G 2014 Proceedings of SPIE 9025 90250X
[6] Cherenkikh P A, Evtikhiev N N, Krasnov V V, Rodin V G and Starikov S N 2015 Proceedings of SPIE 9406 94060O
[7] Starikov S N, Cherenkikh P A, Krasnov V V, Kurbatova E A and Starikov R S 2015 Physics Procedia 73 264–268
[8] Widenhorn R, Dunlap J C and Bodegom E 2010 IEEE Transactions on Electron Devices 57 581-587
[9] Schröder S E, Mottola S, Matz K-D and Roatsch T 2014 Icarus 234 99-108
[10] Rasmussen A 2014 Journal of Instrumentation 9 C04027
[11] Hyun D-K, Ryu S-J, Lee M-J, Lee J-H, Lee H-Y and Lee H-K 2012 Proceedings of SPIE 8303 0E1-0E8
[12] Fridrich J and Goljan M 2011 Proceedings of SPIE 7880 788006
[13] Sugiyama T, Araie M, Riva C E, Schmetterer L and Orgul S 2010 Acta Ophthalmologica 88 723-729
[14] Evtikhiev N N, Shaulskiy D V, Zlokazov E Y and Starikov R S 2012 Proceedings of SPIE 8398 83980G
[15] Kodovský J, Fridrich J, Holub V 2012 IEEE Transactions on Information Forensics and Security 7 432-444.
[16] Princeton Instruments, http://www.princetoninstruments.com/Uploads/Princeton/Documents/Brochures/MEGAPLUS_camera_brochure_Princent_Instruments_B0.pdf
[17] Evtikhiev N N, Starikov S N, Cheryomkhin P A and Krasnov V V 2012 Proceedings of SPIE 8301 830113
[18] Cherenikh P A, Evtikhiev N N, Krasnov V V., Rodin V G. and Starikov S N 2014 Optical Engineering 53 102107
[19] Cherenikh P A, Evtikhiev N N, Krasnov V V., Rodin V G, Starikov R S and Starikov S N 2015 Proceedings of SPIE 9648 96480R