Method of improvement of signal-to-noise ratio of registered shots using dark and light spatial noise portraits of camera’s photosensor

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Abstract

Improvement of the signal-to-noise ratio of registered frames is necessary in scientific, technical and amateur tasks. Dark and light spatial noise portraits of camera’s photosensor can be used for frames quality increase. Earlier method of improvement of the signal-to-noise ratio of shots by use of light spatial noise portraits of camera’s photosensor was proposed. In this paper method of improvement of the signal-to-noise ratio of shots by use of both light and dark spatial noise portraits was analyzed. According to the results of numerical experiments, it was found that the signal-to-noise ratio can be increased up to 50–60 times compared to that one of a single image.

Keywords: signal-to-noise ratio; light spatial noise portrait; dark spatial noise portrait; photosensor; camera; image; frame.

1. Introduction

Improvement of quality of registered frames is important in different scientific fields: image encryption [Theodoridis et al. (2009), Kumar et al. (1997), Duda et al. (2001)], digital holography [Juptner et al. (2005), Evtikhiev et al. (2013, J. Opt. Technol.), Kreis (2005), Cheremkhin, Evtikhiev et al. (2014, J. Phys.: Conf. Ser.), Barsi (2009)], diffractive optics [Soifer (2002)], etc. Decreasing of camera’s photosensor noise allows to improve the shots signal-to-noise ratio (SNR). There are two types of camera’s photosensor noises: temporal and spatial ones [Janesick (2007), Nakamura (2006), Cheremkhin et al. (2014, Opt. Eng.)].

For increase the image SNR, the modification of flat-field correction technique for image SNR increasing was proposed [Evtikhiev et al. (2013, Naukoeimkie technologii), Evtikhiev et al. (2014)]. Unlike the sky or twilight flats
that usually used in flat-field correction technique [Eskridge (2015)], the light spatial noise portrait (LSNP) of camera's photosensor was compensated for spatial noise elimination. LSNP is array of photosensor pixels photo response non-uniformities and commonly used for identification of camera’s photosensor [Pevny et al. (2010), Popescu et al. (2005)]. This modification is aimed to spatial noise decreasing. So it is especially effective after application of others methods of SNR increasing that suppress temporal noise. We investigated numerically in [Evtikhiev et al. (2013, Naukoemkie technologii)] and experimentally in [Evtikhiev et al. (2014)] application of the LSNP compensation method in conjunction with the averaging over frames method.

In this report, we proposed to further increase of the SNR by use of dark spatial noise portrait (DSNP) of photosensor. DSNP is array of dark spatial non-uniformities of the photosensor pixels. We analyzed and investigated application of the DSNP and LSNP compensation method in conjunction with the averaging over frames method. For the numerical estimation of the SNR increase value, we used noise and radiometric characteristics of the consumer and scientific cameras.

2. Description of the modification of flat-field correction technique for SNR increasing by compensation of camera's photosensor DSNP and LSNP

The earlier [Evtikhiev et al. (2014)] proposed modification of flat-field correction technique for image SNR increasing can be described in following way. At first, several frames of a single scene are registered. Then they are averaged into a single image \( I_0(x,y) \) by using the averaging over frames method. And finally compensation of light spatial noise portrait (LSNP) of camera's photosensor is applied according to following equation:

\[
I(x,y) = \frac{I_0(x,y) - DSNP(x,y)}{1 + LSNP(x,y)}
\]

where
- \( I(x,y) \) is obtained image with increased SNR,
- \( LSNP(x,y) \) is LSNP of camera's photosensor i.e. values of pixels photo response non-uniformity,
- \( DSNP(x,y) \) is DSNP of camera's photosensor i.e. values of dark spatial non-uniformity,
- \((x,y)\) is discrete coordinates corresponding to photosensor pixels.

Thus firstly photosensor DSNP should be compensated and only then LSNP.

3. Numerical estimation of the value of SNR increasing by spatial noise suppression using compensation of camera's photosensor LSNP and DSNP

As mentioned above we investigated application of the DSNP and LSNP compensation method in conjunction with the averaging over frames method. In this section, achievable increase of image SNR is estimated using:

- the averaging over frames method;
- application of LSNP compensation method only;
- application of DSNP compensation method only;
- LSNP compensation method in conjunction with the averaging over frames method;
- DSNP compensation method in conjunction with the averaging over frames method;
- DSNP and LSNP compensation method in conjunction with the averaging over frames method.

For obtaining of quantitative SNR estimations with Eq. (4)-(9) characteristics of two cameras were used:

- consumer camera Canon EOS 400D;
- scientific camera Megaplus II ES 11000.
Values of spatial and temporal noises, linear part of radiometric function were measured using the methods and equipment described in [Nakamura (2006), Evtikhiev et al. (2012), Cheremkhin, Krasnov et al. (2014), The European Machine Vision Association (2015)] and are shown in Table 1.

|                          | Canon EOS 400D | Megaplus II ES 11000 |
|--------------------------|----------------|----------------------|
| Linear part of digital signal, digital numbers | 0÷3070         | 0÷3916               |
| Standard deviation of dark temporal noise, digital numbers | 1.6±0.2        | 2.3±0.4              |
| Standard deviation of dark spatial noise, digital numbers | 0.377±0.007    | 0.56±0.04            |
| Camera gain constant, electrons/digital numbers | 9.2±0.2        | 11.88±0.11           |
| Photo response non-uniformity, relative unities | 0.0042±0.0002  | 0.0053±0.0008        |

Modeling of a single and non-single shots registration was conducted by above-mentioned two digital cameras: consumer camera Canon EOS 400D and scientific camera Megaplus II ES 11000. Mentioned in [Evtikhiev et al. (2013, J. Opt. Technol.)] method of construction of digital model of image registered by the camera was used. That method considers values of spatial and temporal noises of digital camera and their linear dynamic ranges. In numerically modeled experiments a standard test halftone image «Lenna» with uniform histogram and size of 512×512 pixels was used.

Figure 1 shows obtained by numerical modeling dependency of registered shots SNR on quantity of averaged frames. Compensation of spatial noise by DSNP allows to increase SNR up to 1 %. Compensation of spatial noise by LSNP allows to increase SNR up to 30 times compared with a single frame and up to 15 times compared with temporal noise suppression only. In order to achieve the almost maximum SNR, averaging over 300÷500 frames is sufficient. Compensation of spatial noise by both the LSNP and DSNP allows to increase SNR up to 50÷60 times compared with a single frame and up to 30 times compared with temporal noise suppression only. Obtained results using LSNP are in accordance with that one presented in [Evtikhiev et al. (2014)].

Thus the case of application of compensation of spatial noise by DSNP only allows to increase the SNR up to 1 %. But if both LSNP and DSNP of camera’s photosensor will be compensated, the SNR can be increased up to 50÷60 times. Also it should be noted that using only LSNP allows to increase the SNR up to 50 times. But DSNP allows to improve the quality of the image up to 20 % additionally in this case.

A single use of the DSNP allow to significant improve the image quality in the case of a little signal values, i.e. for frames in the case of a low illumination. In result the quality of the images after LSNP compensation can be increased several hundred percent additionally.

In the case of halftone images, a single use of the DSNP don’t allow to significant improvement of the quality (only for values about several percent). But DSNP compensation can significantly increase the halftone image SNR after use of the LSNP compensation (for values about several ten percent). This can be seen compared the violet and black lines shown in the Figure 1a,b.
Fig. 1. Obtained by numerical experiments dependencies of image SNR on quantity of averaged frames with and without light and dark spatial noise portraits for cameras: Canon EOS 400D (a) and Megaplus II ES 11000 (b).

4. Conclusion

Method of improvement of the signal-to-noise ratio of shots by use of light and dark spatial noise portraits of camera’s photosensor was analyzed and numerically verified. It allows suppressing spatial noise in registered images. The method requires knowledge of light and dark spatial noise portrait of used photosensor.

Numerical experiments on estimation of SNR increase for two cameras were performed: consumer camera Canon EOS 400D and scientific camera Megaplus II ES 11000. During modeling measured noise and radiometric characteristics of these cameras were used.

Thus the case of application of compensation of spatial noise by DSNP only allows to increase the SNR up to 1%. But if both the LSNP and DSNP of camera’s photosensor will be compensated, the SNR can be increased up to 50÷60 times. DSNP allows to improve the quality of the image up to 20% additionally compared with the use of the LSNP compensation method only.
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