Information Model for Determining the Significance of Factors Influencing the Level of Digital Noise in Photographic Images

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Abstract

A digital photo today is accessed by practically all persons interested to fix interesting moments. Except satisfaction of aesthetic requirements of ordinary consumers, a photo is the means of receipt of publishing graphic originals in the field of publishing. Regardless of tasks that put to the photo, the most important requirement is to carry to the consumer a good finished visual information without distortion.

Digital noise (harmful signal) in digital image is identified as a lack of structural descriptions and on condition of exceeding maximum of legitimate values requires a correction. As facilities of graphics editors for the decline of digital noise predetermine the decline of sharpness simultaneously, that is why it is necessary to realize the process of receipt of photographic image with the least sound-level.

Many factors of influence are known on the level of noisemaking in digital photographic representation. In this article is described an informative model, that allowed to distinguish main factors that influence on structural descriptions in a most degree. It is analysed, that part of factors, that are permanent (physical sizes of photosensitive matrix, closeness of placing of pels, technology of making of matrix and description of materials), have most influence on the level of noisemaking.

Other factors (ISO, time of exhibiting, condition of illumination) are variables that the user chooses each time in accordance with the terms of photographing. Certainly, that the protracted displays induce more subzero level of digital noise, than high value of light-sensitivity, that it follows to take into account at a low level illumination in plane shot.

It was certain that high ISO causes the high level of noisemaking, regardless of technical class of the camera that is equipped by the identical type of photosensitive matrix with even physical sizes.

During experimental research is found, that on the photoimage digitised in a raw-format, the level of both types of digital noise is higher, than on the photoimage digitised in the format of jpeg.

Research results allow to choose the optimal terms of exhibiting of image at the low level of illumination, to provide the high indexes of quality.

Keywords1

Digital noise, ISO, terms of exhibiting, photoimage, photosensitive matrix, photocamera, digitized, physical sizes of photosensitive matrix, informative model, raw-format, jpeg, closeness of placing of pels, technology of making of matrix, description of materials.

Introduction

More than a hundred years have passed since the appearance of photography, and the issue of obtaining a high-quality photo remains relevant to this day. The following indicators of the quality of a digital photographic image are distinguished: tone reproduction (exposure), color balance

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(reproduction of memorable colors and gray balance), reproduction of small details and clarity (sharpness) of the image, the presence of defects in the image (noise, etc.) - the so-called structural characteristics ... The last two criteria are especially critical for human vision. If the tone reproduction and color tone of the photographic image is difficult for an ordinary observer (reader) to quickly assess with the original, then deficiencies in the structural characteristics of the image are easily fixed visually and are recognized by the human brain as an undesirable phenomenon. The viewer perceives the surrounding space as sharp and wants to see the illustration in the publication with the same sharpness and with clearly reproduced details.

Digital noise is still a weak side of digital photography, since increasing the matrix resolution leads to a decrease in the threshold light sensitivity. If there is insufficient light in the frame, to obtain a normally exposed photo, you should increase the shutter speed or light sensitivity. This inevitably leads to noise generation. There are also a number of other purely technical causes of noise.

Related Works

The photographic process in general is very flexible as many factors influence the final result. In digital technologies, the issue of obtaining photographs with satisfactory structural characteristics is especially acute. The first thing that determines the level of noise in photography is the technical characteristics of the most light-sensitive medium - the photocell array. As known from the literature, matrices formed from complementary metal oxide semiconductors (so-called CMOS matrices) form an image with a higher noise level than CCD matrices (charge coupled devices) [4, 7]. The reasons for the high noise level are explained by the presence on the matrix in each individual elementary focal analog-to-digital converter and other microcircuits for digitizing the analog signal directly on the matrix. However, even with such characteristics, CMOS matrices have found wide application in digital photography due to their low cost and ease of manufacture. On the other hand, large CCDs cannot be equipped with photographic equipment due to their significant cost, and with the small dimensions of this class of matrix, the unit cell size at modern high resolution becomes critically small. Thus, small-sized unit cells again produce a harmful signal - noise. CMOS-matrices of components in digital photographic equipment of the highest technical class with interchangeable optics, while the size of the matrix is equal to a full frame or half of a film frame [13, 14]. Under such conditions, it is possible to significantly reduce the noise level, but it is impossible to completely get rid of this negative phenomenon. CCDs of small dimensions from components in the segment of amateur photographic equipment. The small size of the matrix allows not to significantly increase the cost of photographic equipment and to provide a certain average level of quality, but also the small size of the sensor again leads to noise generation. So, it is impossible to avoid a completely negative phenomenon of noise formation with all constructive types of matrices. From this, it can be assumed that when photographing with any class of photographic equipment, under certain exposure conditions, photographic images with a certain level of noise will be formed.

In addition to the features of photosensitive matrices, the level of noise in a photographic image is affected by the technical parameters of photography and the file format with a digitized image. As you know, the photographic process is very flexible and the final result (qualitative and quantitative characteristics of the photographic image) is influenced by a number of factors. So, in particular, exposure and photosensitivity of the photocell matrix determines not only the gradiation of the photo image, but also the noise level. In low light conditions, either increase the shutter speed or the ISO speed to achieve a satisfactory tone. In both cases, according to the references [1, 10], there is a threat to get a noisy image, as the shutter speed is increased, the sensors generate a harmful signal (noise), because they are not designed for prolonged exposure to light energy. An increase in the photosensitivity also leads to the appearance of noise, since a higher photosensitivity of the photocell array is achieved by a different degree of amplification of the output signal. Since each sensor (unit cell) always generates a certain proportion of the harmful signal, the amplification of the useful signal inevitably leads to the amplification of the harmful signal by the same amount. As a result, the noise becomes more noticeable.

Another likely reason for the increase in the noise level is the process of digitizing information into the JPEG format. Literature sources claim that RAW digitization provides low noise [8, 5].

Since there are so many variables that affect the level of digital noise in photographic images, it is important to organize them and determine which ones influence the most. Such a study will give a reasonable answer about the need to choose certain technical parameters of exposure in order to achieve the best quality indicators of a digital photographic image.

Construction of an information model to determine the importance of factors influencing noise generation

From the very beginning of digital photography, digital photo noise has been one of its main problems. Digital noise is a photographic defect caused by the peculiarities of the photosensor of a digital camera. Digital noise is manifested in the form of randomly located dots of different brightness and color. It is especially noticeable on plain surfaces - sky, skin, shadow areas.

There are two types of digital noise. Fixed noise caused by different sensitivities of individual matrix elements. This is a special characteristic of a particular matrix that does not change over time. This category of noise lends itself well to correction with simple noise reduction algorithms in digital photography. Constant digital noise appears the same in all photographs taken with a particular camera model and is associated with “hot” and “broken” pixels. Random noise caused by different reactions of the same matrix element over time, from shot to shot, around some average, "nominal", or "correct" value. Random digital noise appears as randomly colored dots randomly scattered throughout the frame. This type of noise is clearly visible on plain surfaces (sky, skin, shadows).

Random digital noise is classified into types:

• Luminance digital noise (luminance noice).

• Chromatic digital noise (chrominance noice).

Luminance noice appears in the image as small dark dots (or spots) and often resembles the grain of conventional photographic film. Chromatic digital noise (chrominance noice) in the image appears as small spots (dots) of a different color, different from the color of the background or object on which the noise appears (which is why it is very clearly visible). Chromatic digital noise is especially noticeable to the observer and unpleasant to perceive. In color photographs, noise has a different intensity in each color channel, which gives it a specific color. Factors that impact the level of digital noise [2]:

1. Physical size of the photosensor and its resolution. The smaller the physical size (dimensions) of the photosensor and the higher its resolution, the higher the noise level for a given matrix. With the unchanged production technology of photosensors and constant matrix dimensions, one should not chase megapixels.

2. Sensitivity of the photosensor (ISO sensitivity). In fact, the sensitivity of the photosensor is constant, only the signal gain changes. The harmful signal (noise), which is always present in the image, is amplified in proportion to the amplification of the useful signal in the process of increasing the photosensitivity. The higher the ISO, the more digital noise you will see in the photo (more distortion occurs when the signal is amplified).

3. Technical parameters of the matrix (defects in the silicon crystal lattice, impurities, dead pixels, etc.).

4. Pixel density (matrix cell size). The optimal size is in the range from 6 to 11 microns. In compact cameras, the cell size is 3-5 microns, which causes a high level of noise.

5. Shutter speed or exposure time of the frame. The level of digital noise directly depends on the temperature of the photosensor, and the higher the temperature, the higher the noise level in the image. The photocells of the matrix are not suitable for long-term recording of a light signal. The longer the exposure, the higher the temperature of the sensor, and accordingly, the higher the noise level. With burst shooting, the sensor temperature rises, so the last shot in the burst will have the highest noise level. The faster the shutter speed, the less digital noise. With a long exposure (1 second or more), the digital noise level increases. Not in all cases you can set a fast shutter speed.

6. Sensor production technology. In general, CMOS matrices generate more noise than CCDs and this is due to their technical features of processing light information.

7. Conditions (lighting level) that determine the choice of exposure time and photosensitivity.

To solve one of the tasks of the general research, namely, the development of a multilevel model of factors influencing the level of digital noise, a methodology was chosen that provides for: identifying a set of factors directly related to the formation of noise; formalizing the task of factors; formation of an initial directed graph of connections between factors; building a binary reach matrix; construction of tables recording the presence or absence of relationships between factors; the implementation of iterative procedures for processing tables to establish the levels of importance of factors; synthesis using the method of structuring relations [4] of a multilevel model of the priority influence of factors on the process of forming digital noise.

Consider the procedure for the formation of digital noise as a function, the arguments of which will be given below factors.

$$PR = F\left(s_1, s_2, s_3, s_4, s_5, s_6, s_7\right), \quad (1)$$

where s_1 – physical dimensions of the matrix (PDM); s_2 – photosensitivity (PHS); s_3 – exposure time (EXS); s_4 – pixel density (PDS); s_5 – conditions (lighting level) (CLL); s_6 – technical parameters of material (TPM); s_7 – type of photosensitive matrix (TFM).

Taking into account expert judgments, we build the initial graphic model (directed graph), pair effects (connections) between factors (Fig. 1).

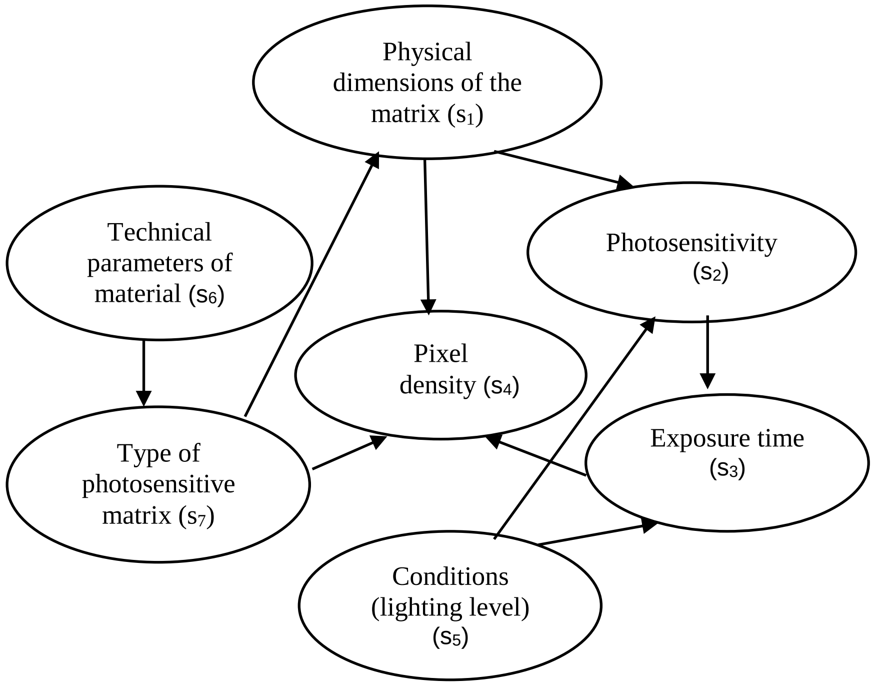

Figure: 1. Graphic model (directed graph) of paired influence (connections) between the factors that determine the level of noise production

Output graph Fig. 1 we use to compile factors according to the importance of influence on the process under study, the result of which will be a multi-level model of factors influencing the level of digital noise. For the synthesis of a linguistic model, we will use the means of matrix theory and system analysis [3, 6].

Using the existing graphical model - an analogue of the semantic network, we construct a binary matrix of reach (Table 1), which simulates the possible options for connections between factors located at the vertices of the graph.

The construction of the matrix is carried out by filling in the table, the binary elements of which are determined according to such a logical rule:

$$b_{ij} = \begin{cases} 1, \text{ if from } b_i \text{ you can get in } b_j \\ 0, \text{ if from } b_i \text{ can't get into } b_j \end{cases} \quad (2)$$

Almost the top s_j $(j=1,2,...,7)$ the initial graph of Fig. 1 is considered reachable relative to the top s_i $(i=1,2,...,7)$ from the latter you can get into s_j in an arbitrary indirect way, taking into account the transitions through other vertices. The result of the analysis of all vertices leads to a subset of reachable vertices $D(s_i)$.

Table 1

Reach matrix

	PDM	PHS	EXS	PDS	CLL	TPM	TFM
PDM	1	1	1	1	0	0	0
PHS	0	1	1	0	1	0	0
EXS	0	0	1	1	0	0	0
PDS	0	0	0	1	0	0	0
CLL	0	1	1	1	1	0	0
TPM	1	1	1	1	1	1	1
TFM	1	0	0	1	0	0	1

At the same time the top s_i precursor to the peak s_j, if it is reached from it, and their collection forms a subset $P(s_i)$. Finally, the section of the subsets of reachable and predecessor vertices forms a subset:

$$Z(s_i)=D(s_i)\cap P(s_i) \qquad (3)$$

which determines a certain level of priority of the action of the factors referred to these peaks. An additional condition in this case is to ensure equality:

$$P(s_i)=Z(s_i) \qquad (4)$$

Implementation of dependencies (3) and (4) using iterative tables leads to the formation of appropriate levels, the initial of which is the highest in terms of the priority of impact on the process under study.

Subset $D(s_i)$ – the numbers of the reachable vertices or the numbers of the unit elements of the corresponding rows of the reachability matrix are entered into the second column of the table; the third column defines a subset of predecessor vertices $P(s_i)$ – the numbers of single elements of the columns of this matrix. As a result of fulfillment of dependence (4), a certain level of the hierarchy of factors is formed.

As you can see from the table. 2, the coincidence of numbers is fixed for factors 1, 4, 6, 7 - physical dimensions of the matrix, pixel density, technical parameters of the material, type of photosensitive matrix. These factors, one after another, consider their sequence according to the level of priority of influence on the digital noise production process.

According to the methods of system analysis and mathematical modeling of hierarchies [3, 11], we remove from the table. 2 the first, fourth, sixth and seventh rows, and in the second and third columns we delete the numbers 1, 3, 6, 7. We get a table that serves as the basis for calculating the next iteration - the basis of the next most important level of factors.

Table 2

Iteration matrix

i	$D(s_i)$	$P(s_i)$	$D(s_i)\cap P(s_i)$
1	1,2,3,4	1,6,7	1
2	2,3,5	1,2,5,6	2,5
3	3,4	1,3,4,5,6,7	3,4
4	3	1,3,4,6,7	3
5	2,3,4,5	2,5,6	2,5
6	1,2,3,4,5,6,7	6	6
7	1,4,7	6,7	7

Analysis of the table. 3 is carried out according to the above algorithm. It is easy to see that the coincidence of the numbers is fixed for factors 2 and 5 - light sensitivity and conditions (lighting level), which form the next level of the hierarchy from the top.

Table 3
Iteration matrix

i	$D(s_i)$	$P(s_i)$	$D(s_i)\cap P(s_i)$
2	2,3,5	1,2,5,6	2,5
3	3,4	1,3,4,5,6,7	3,4
5	2,3,4,5	2,5,6	2,5

Iterative procedures similar to those described above lead to table. 4, in which there are no lines with numbers 2 and 5, and these numbers are removed from the second and third columns of the table. Table 4, which determines the last factor, which is the exposure time, and completes the iterative process of obtaining the initial data to form the final multi-level model.

Table 4
Iteration matrix

i	$D(s_i)$	$P(s_i)$	$D(s_i)\cap P(s_i)$
3	3,4	1,3,4,5,6,7	3,4

Using the data of iterative analysis and taking into account [9, 12], we synthesize a multilevel structured graphic model (Fig. 2), which clearly reflects the place of each of the factors and reproduces the connections between them, specified in the original model (Fig. 1).

In the one shown in Fig. 2 of the multilevel model, the priority of the action of factors on the process of forming digital noise is determined by the level of its placement.

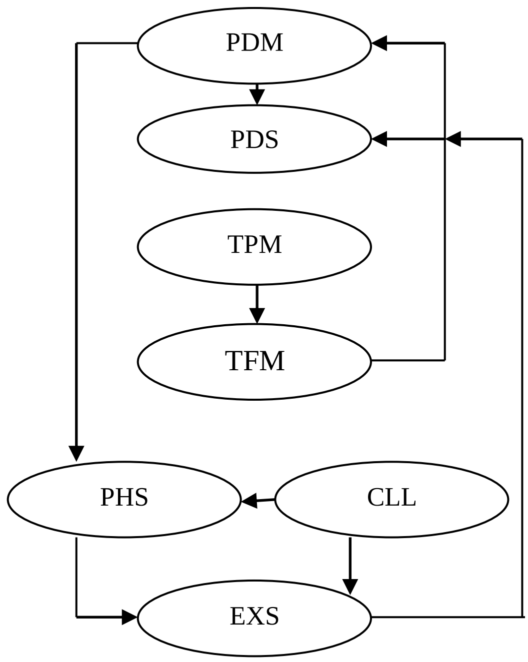

Figure: 2. Multilevel model of factors influencing digital noise

Thus, the information model confirmed that the greatest influence on the level of noise generation is the physical dimensions of the photosensitive matrix and the pixel density, the technical parameters of the material from which the photosensitive matrix itself is made, the type of the photocell matrix. These parameters are unchanged, given to the user of a certain model of a digital camera by its very technical class and manufacturer. Other factors are variable: light sensitivity, exposure time and lighting conditions. They are chosen at each exposure in particular. Therefore, in the next part of the study, we will establish which of the listed variable factors affects the noise level of a digital photographic image to a greater extent.

Investigation of the degree of influence of variable factors on the level of digital noise

As an object for studying the structural characteristics, we use a stepped achromatic scale made with photographic method. We will measure the noise level in the semitone section, since it is this tonal range that is most informatively saturated. In order to create certain lighting conditions, mercury gas-discharge (fluorescent) lamps TL'D / 950 de Luxe by Phillips were used as a light source. The color temperature of the radiation of the specified source is 5300K. Under the described lighting conditions, exposure was carried out with two models of SLR cameras from the same manufacturer (EOS 800D and EOS 80D from Canon) at different levels of light sensitivity and shutter speed (exposure time). The resulting digital photographs were digitized into two file recording formats: jpeg and cr.2 (raw format from Canon).

The next step is to evaluate the level of digital noise in the obtained photographic images. One of the serious problems of computer graphics is that an adequate criterion for assessing the loss of image quality has not yet been found. And it is constantly lost: when digitizing, when transforming into a limited color gamut of a certain color model, when converting to another color reproduction system for printing, etc. As the most optimal method for assessing quality, you can apply the standard deviation criterion of pixel values:

$$d(x,y)=\sqrt{\frac{\sum_{i=1,j=1}^{n,m}\left(x_{i,j}-y_{i,j}\right)^2}{n^2}} \quad (5)$$

On the photographic images obtained according to the stated method, the level of noise was measured in a graphic editor PhotoShop by parameter Std Dev on the «Histogram» palette. The smaller the numerical value Std Dev, the lower the noise level. The obtained experimental results are shown in Fig. 3-5.

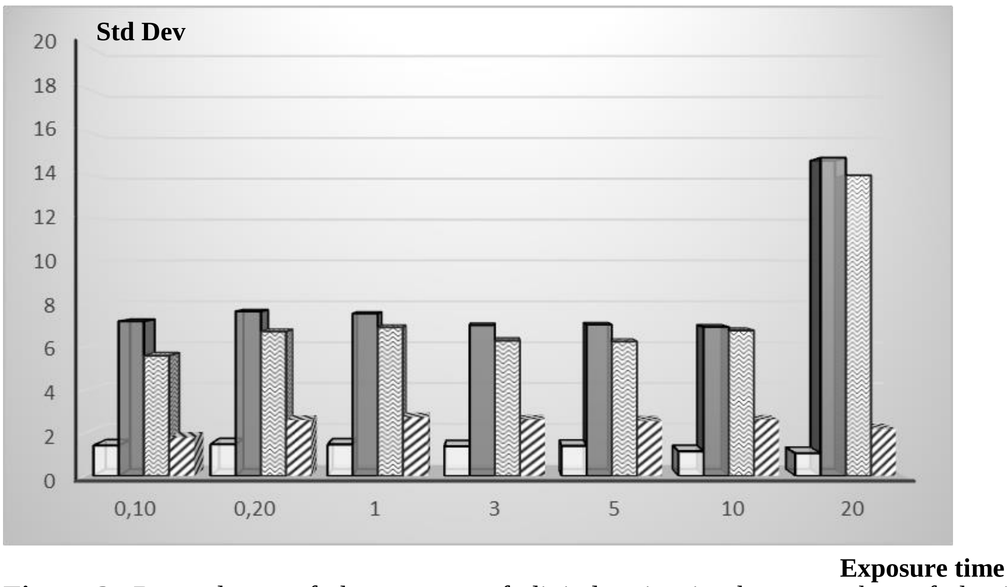

Figure:3. Dependence of the amount of digital noise in the penumbra of the image on the exposure (format jpeg and cr2, camera EOS-800D)

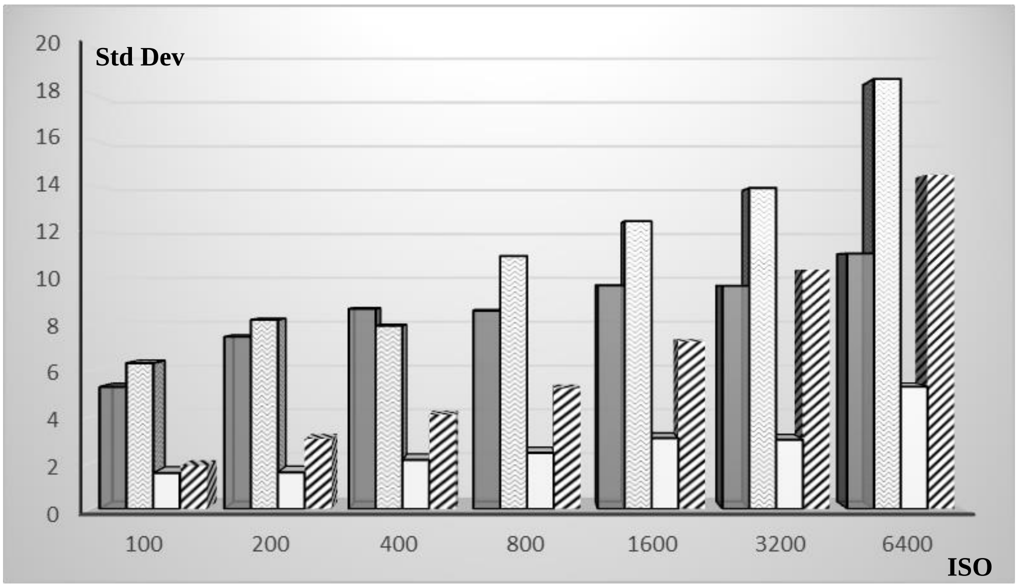

Figure: 4. Dependence of the amount of digital noise in the penumbra of the image on the photosensitivity (format jpeg and cr2, camera EOS-800D)

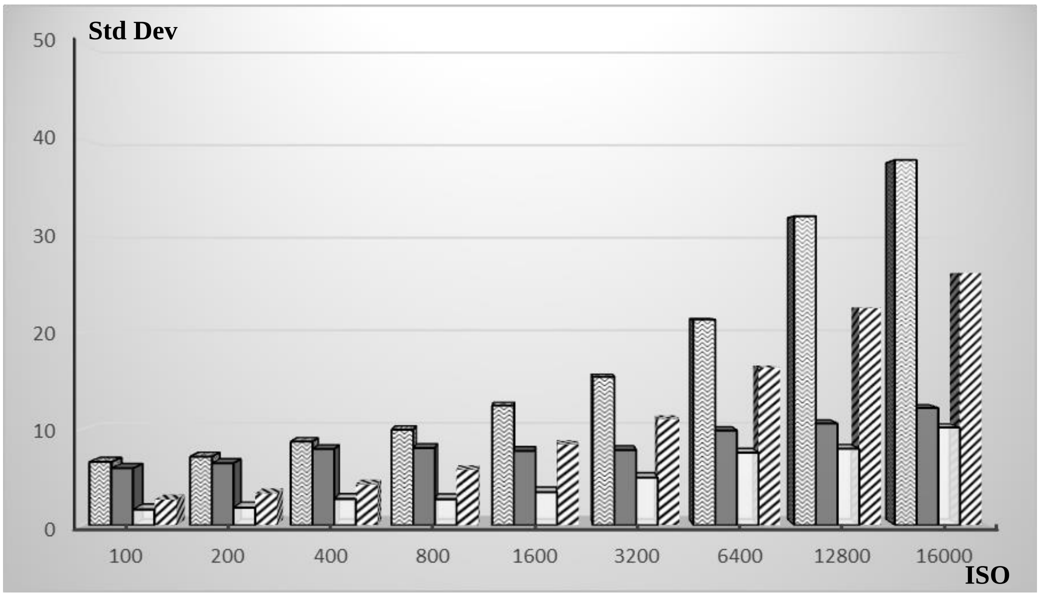

Figure: 5. Dependence of the amount of digital noise in the penumbra of the image on the photosensitivity (format jpeg and cr2, camera EOS-80D)

- the value of the luminance noise in the photo image in the format cr2
- the value of the luminance noise in the photo image in the format jpeg
- the amount of color noise in the photo image in the format cr2
- the amount of color noise in the photo image in the format jpeg

Let's analyze the results obtained. In fig. 3. shows a diagram of the distribution of the magnitude of color and brightness noise in photographs obtained with long exposures and digitized in two file formats. A certain level of color and brightness noise is formed in the photographic images, the value of which is stable in a fairly wide interval of exposures. The magnitude of the brightness noise when photographing with long exposures does not exceed the maximum permissible value (Std Dev$\leq$3), and the level of color noise in the photo image, on the contrary, significantly exceeds the permissible value. A particularly sharp jump in the noise level, which exceeds the permissible value by almost five times, occurs at a shutter speed of 20 seconds. Such digital noise is identified by the observer's eye as a defect in the photographic image. Another important conclusion that can be drawn from this study is that the raw format of digitization does not provide the best structural characteristics of digital photographic images.

The effect of photosensitivity on the structural characteristics of digital photographic images is shown in Fig. 4 and 5, the results indicate a significant increase in noise production in photographs obtained with a sensitivity already above 100-200 ISO. With an increase in photosensitivity, this tendency continues and the noise level only increases. In the photo image taken at ISO 6400, the color noise level is almost three times the limit. At the same time, there is a tendency for the level of color noise to increase with each increase in photosensitivity step by step.

As evidenced by the experimentally obtained data, the value of digital noise at high values of photosensitivity is much higher than at long exposures, which is consistent with the results of mathematical modeling presented at the beginning of this article. Therefore, we can recommend users of digital SLR cameras in low light levels to give preference to long exposure as opposed to high light sensitivity.

Analysis of the structural characteristics of photographic images obtained under similar photographing conditions and digitized in the raw file format indicates that the level of color noise is significantly higher in these images. So, with a photosensitivity of 6400 ISO on a photo image in a jpeg file format, the color noise level is in the order of Std Dev = 11 (Fig. 4), and on a photo image in a raw file format, the color noise level is Std Dev = 19, that is, almost twice as high. A similar trend is typical for photographs obtained by two cameras of different technical class (Fig. 5), therefore, it can be assumed that this level of noise generation is due to the raw format recording algorithm in the software of Canon cameras, but does not depend on the development of the software itself. This result is interesting, since it is not described in any literary sources.

Conclusion

Shooting at high ISO values results in a high level of color and brightness digital noise in the photo image. Therefore, the recommended optimal light sensitivity can be considered ISO 100-200, depending on the specific camera model. Long exposure times generate low-level digital noise, so it can be argued that light sensitivity is the most influential factor for noise production. Based on the obtained practical results, which are confirmed and developed by the information model, it is possible to recommend users to give preference to long exposure as opposed to high photosensitivity.

The camera model and software development do not determine the level of digital noise in the photographic image. Cameras of different technical classes, but equipped with the same size and type of photosensitive matrix, produce photographic images with the same level of digital noise.

Digitization in raw format leads to the formation of a significant level of color and brightness noise, which can be explained by the peculiarities of digitizing information when recording data in raw format, namely, the lack of image data processing by the camera software, including noise suppression algorithms at high light sensitivity.

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