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The information technology for image filtering and storing obtained under low light conditions

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ABSTRACT

This work is devoted to development of information technology for real noise image filtering and storing obtained under low light condition. The information technology is designed to reduce the size of the image (video) archive, through the use of image processing methods. The structure of information technology is proposed. It includes input data, color models, image processing methods (filtering, compression, blocking effect reduction, coding and transmission), algorithms and software. The developed information technology depending on image type, task and result requirements performs image processing with appropriate filtering methods and has the possibility of encoding and transmission obtained images. The information technology allows reducing the size of the video archive in a video surveillance system with MPEG-4 (XVID) and H.264 video codec, while maintaining acceptable quality.

Keywords: information technology, image processing, image filtering, image storing, bilateral filter, multi resolution analysis, wavelet transform, blocking effect reduction.

1. INTRODUCTION

Digital image processing is currently widely used in telecommunication systems, radio and sonar detection, seismology, robotics, radio astronomy, medicine, and the like. The transition to digital broadcasting, the widespread use of various networks, including the Internet contributes to the development of the direction of signal processing as well[1].

Nowadays, the digital image processing devices are characterized by the problems of a constant increase in the amount of information that is processed, increasing requirements for processing quality, and working under difficult conditions (low signal-to-noise ratio). All this stimulates the development of new methods and more sophisticated algorithms used in the digital image processing system[2,3].

At obtaining images in the dark, its quality is significantly reduced due to the sharp increase of noise, which leads to the appearance of image grain. Noise caused by signal amplification substantially affects the possibility of compression[4,5]. Modern compression algorithms perceive the noise as useful information, and it results strongly in the reduction of compression efficiency. The size of transmitted data increases, and the relative amount of information decreases. In addition, during compression, the whole image is divided into blocks, which ensures coding efficiency. However, additional distortions are imported into the image in the form of blocking effect that appears on the boundaries between two adjacent blocks[6,7,8].

Therefore, an important place in the digital image processing is the task of improving the signal-to-noise ratio, which determines the necessity of the preliminary image processing before their classification and analysis, at the recognition of models and decision-making[9,10].

Improving the quality of images is achieved by using a filtering procedure, which is the most time-consuming and complex stage of pre-processing. There are many different filtering methods with their own advantages and disadvantages. But filtering methods, as a rule, specialize in suppressing one particular type of noise. There are no universal filters that identify and filter all types of noise. The application of a particular method depends on a specific task[11,12].

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Therefore, the development of information technology (IT) processing and improvement of image quality both for human visual perception and for solving problems related to machine perception of images, is an actual and important scientific and technical task[13].

2. THE INFORMATION TECHNOLOGY DEVELOPMENT

The proposed information technology for image filtering and storing obtained under low light conditions consists of the following elements (Fig. 1):

- input data;
- models;
- processing methods;
- quality assessment criteria;
- algorithms;
- software.

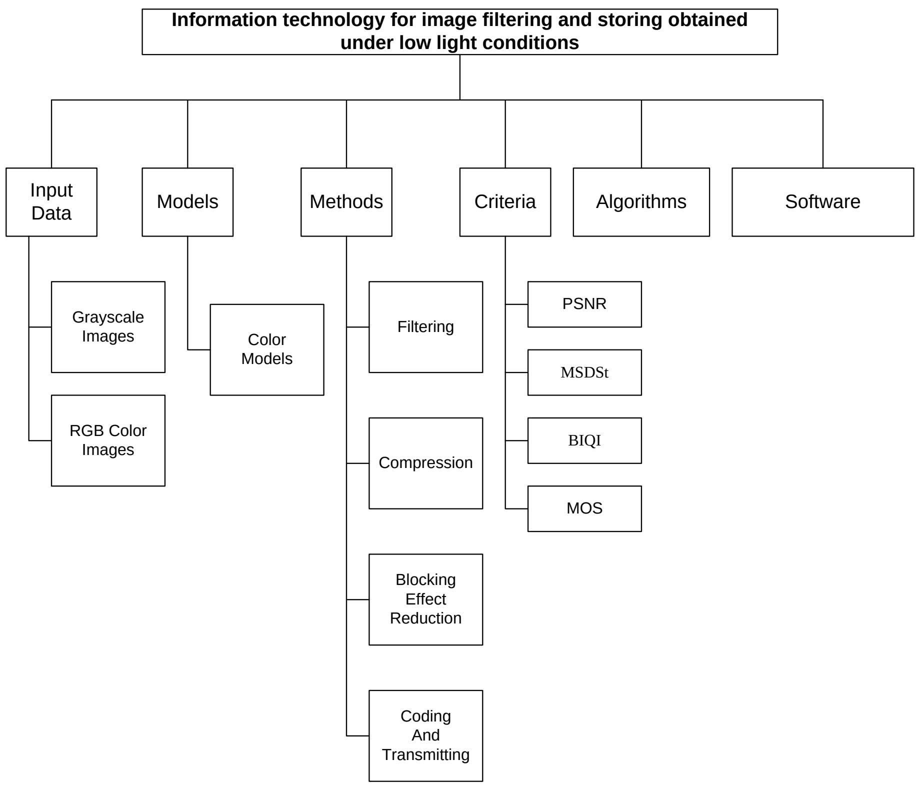

Fig. 1. The structure of information technology of filtering and storing of images obtained under low light conditions

The input data of the proposed IT are grayscale and/or color RGB images that are corrupted by noise and/or blocking effect.

Models used in information technology are color models for converting color images into a form convenient for processing.

In literature there are many image denoising methods. The following filtering methods have been analyzed: Gaussian smoothing model, Yaroslavsky neighborhood filter[3] and SUSAN (Smallest Univalue Segment Assimilating Nucleus) filter, bilateral filter; PDE based methods: anisotropic filtering model[8], Rudin-Osher-Fatemi total variation model[11]; filters in frequency domain: hard and soft thresholding[12,14], Zhou-Wang wavelet total variation[15]; non-local means algorithm[16].

For the developed IT to process color images, it is suggested to use a cross-channel paradigm[17].

For a given three-channel color space decomposition $\left(\vec{i}, \vec{j}, \vec{k}\right)$, a color image:

$$\vec{u}(x) = u_1(x)\vec{i} + u_2(x)\vec{j} + u_3(x)\vec{k} \quad (1)$$

and a cross-channel paradigm will be[11]:

$$CR\left(\vec{u}(x)\right) = CR\left(u_1(x)\vec{i} + u_2(x)\vec{j} + u_3(x)\vec{k}\right) = CR_1\big(u_1(x)\big)\vec{i} + CR_2\big(u_2(x)\big)\vec{j} + CR_3\big(u_3(x)\big)\vec{k}, \quad (2)$$

where CR_1, CR_2 та CR_3 are different, but correlated filters defined on three channels.

In the standard luminance-chrominance decomposition, such as *Lab* and *YCrCb*, the luminance includes a blue channel, where noise concentrates. As a result, the luminance channel can be noisy, and therefore substantial denoising will have to be performed on it. This can be adversely affecting the quality of the denoised color image. To get around this problem we use the modified *YCrCb* color space (*mYCrCb*). The luminance channel Y in *mYCrCb* is a linear combination of only the green and the red channels. More precisely, the *mYCrCb* color space is obtained via a linear transform from RGB space[17]:

$$\begin{aligned} Y_m &= 0.667G + 0.333R \\ Cr_m &= (R - Y)/1.6 \\ Cb_m &= (B - Y)/2. \end{aligned} \quad (3)$$

The methods that are used in this information technology include[18,19,20]

- grayscale and RGB color images filtering methods;
- compression methods;
- blocking effect reduction methods after the compression stage;
- methods that implement the coding and transmission of processed grayscale and color images[21].

For filtering grayscale images, it is reasonable to use the multi resolution filtering method that is based on wavelet transform and bilateral filtering (Fig. 2).

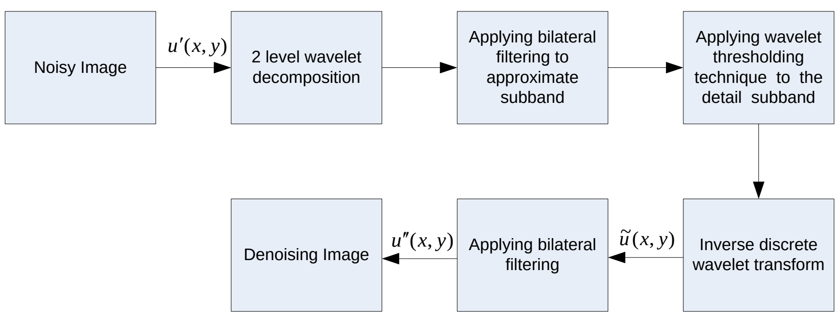

Fig. 2. Scheme of image denoising process

For filtering color images it is proposed to use the cross-channel Non Local Means Filter.

Let:

$$\vec{u}(x) = u_Y(x)\vec{\imath} + u_{Cr}(x)\vec{\jmath} + u_{Cb}(x)\vec{k}, \quad (4)$$

where $\vec{\imath}$, $\vec{\jmath}$, $\vec{k}$ is the *mYCrCb* color space decomposion.

Then,

$$CNL\big(\vec{u}(x)\big) = CNL\big(u_1(x)\vec{\imath} + u_2(x)\vec{\jmath} + u_3(x)\vec{k}\big) = CNL_1\big(u_Y(x)\big)\vec{\imath} + CNL_2\big(u_{Cr}(x)\big)\vec{\jmath} + CNL_3\big(u_{Cb}(x)\big)\vec{k}\ . \quad (5)$$

Note that, in NLM filter

$$NL(u)(i) = \textstyle\sum_{j \in I} w(i,j)u(j), \quad (6)$$

where:

$$w(i,j) = \frac{1}{Z(i)} e^{-\frac{\left\| u(N_i) - u(N_j) \right\|_{2,a}^2}{h^2}}, \quad (7)$$

now let:

$$CNL_1(u_Y)(i) = \sum_{j \in I} w_{Y,h_0}(i,j) u_Y(j), \quad (8)$$

$$CNL_2(u_{Cr})(i) = \sum_{j \in I} w_{Y,h_1}(i,j) u_{Cr}(j), \quad (9)$$

$$CNL_3(u_{Cb})(i) = \sum_{j \in I} w_{Y,h_2}(i,j) u_{Cb}(j), \quad (10)$$

where:

$$w_{Y,h}(i,j) = \frac{1}{Z(i)} e^{-\frac{\left\| u_Y(N_i) - u_Y(N_j) \right\|_{2,a}^2}{h^2}}. \quad (11)$$

For Y channel we may perform the filter more slightly, so we choose a small h_0. For Cr, Cb channels, we choose larger h_1 and h_2, to obtain strong blurring effect. We also notice that in CNL_2 and CNL_3, the weights were computed by grey values in Y, which means the similarity of blocks will be determined by Ychannel, and then performed in Cr andCb channels[22,23].

To compress images, it is suggested to use the JPEG method[24].

To reduce the blocking effect after the compression stage, it is advisable to use a dyadic wavelet transform and an optimal interpolation technique for processing each row and each column to compress image matrix.

As a method that implements encoding and transmission of processed grayscale and color images, it is suggested to use the method of encoding and transmitting information with protection. The method includes actions in the following sequence[25,26]:

On the transmission side:

– reading an array of discrete information in the size of a standard block;
– calculating Walsh functions;
– obtaining Walsh functions numbers for approximating the initial message;
– transmitting the block size and the numbers of the Walsh functions to the channel.

On the receiving side:

– receiving the block size from the communication channel;
– accepting the Walsh functions numbers and restoring the Walsh's functions themselves;
– composing the binary Walsh functions and restoring the information;
– storing the received data.

To the criteria for the processed image quality assessment belong:

– the peak signal-to-noise ratio (PSNR) - to evaluate the image quality after the filtration stage;
– the mean square difference of slope (MSDSt) to evaluate the image quality after the stage of blocking effect reduction;
– the blind image quality index (BIQI) - for quantifying image quality;
– the mean opinion score (MOS) - for subjective evaluation of image quality.

Based on the methods of filtering, compressing, reducing the blocking effect, encoding and transmitting, appropriate algorithms and software are developed[26,27].

In order to show the functional opportunities of the information technology of filtering and storing images under low light conditions, it has been developed a scheme for organizing information processes and procedures (Fig 3).

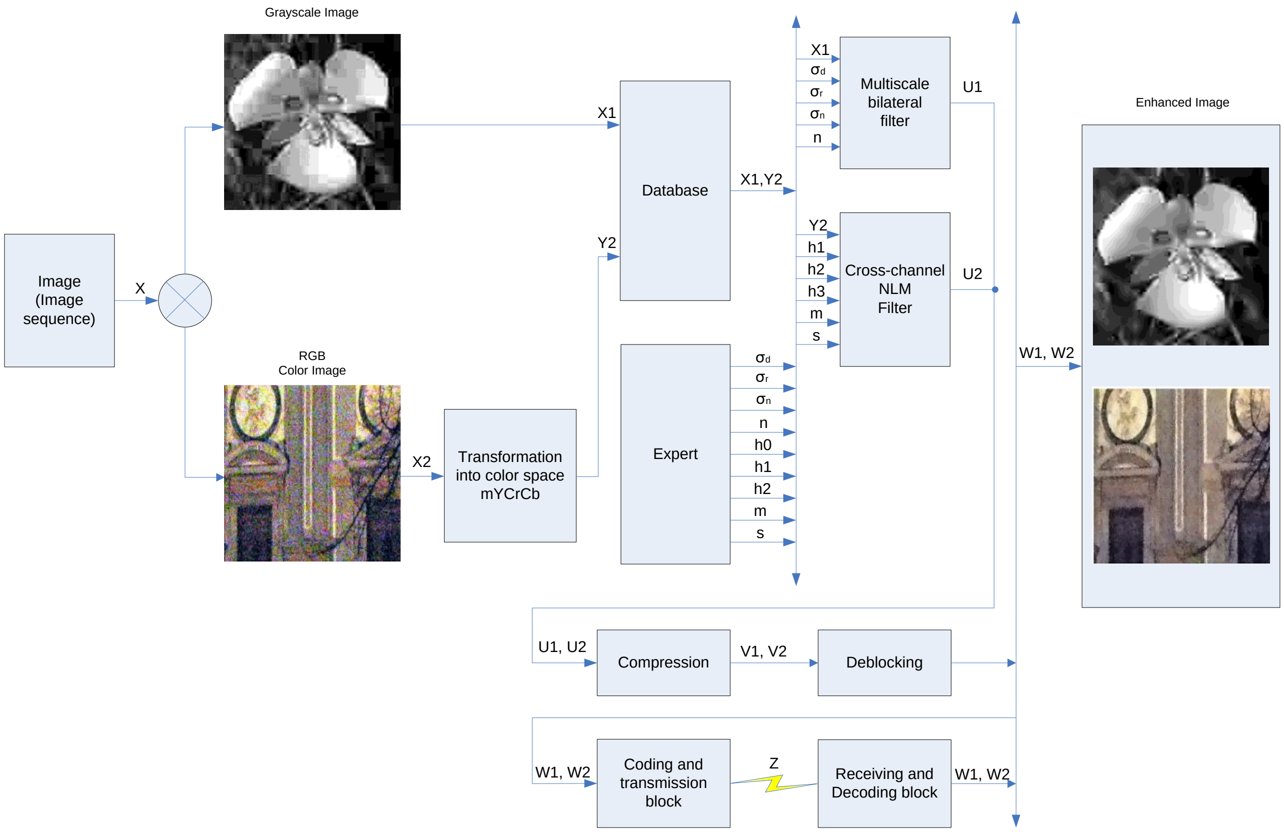

Fig. 3. The scheme for organizing information processes and procedures within the framework of the obtained information technology

At the stage of obtaining information a digital image or a sequence of images are given on the input of information technology. Information technology in automatic mode determines the type of input image (sequence) – grayscale *X1* or color *RGB* image *X2*.

At the stage of information transformation, if the information technology input enters *RGB* image *X2*, the image is converted from the *RGB* color space to the *mYCbCr* color space in order to present the image in a convenient form for further processing. The image *Y2* is a result of the transformation stage.

At the stage of data accumulation, the *X1* and *Y2* digital images are recorded to the database.

At the data processing stage, depending on the type of images, the task and the requirements for the result, the appropriate methods are applied: the multi resolution filtering method, the cross-channel NLM filter, the compression method, the deblocking method.

If it is necessary to process the grayscale image *X*1, then one of two methods can be applied to it, depending on the task. If necessary to filter the image from noise a multi resolution filtering method is applied as a pre-processing stage before compression. If necessary to reduce the distortion that occurs after image compression a method of blocking effect reduction is used.

If it is necessary to process the color image *Y2*, then the cross-channel NLM filter is applied as a pre-processing stage before compression.

For each of the methods, the expert can set the appropriate parameters to achieve the desired result. The specified parameters of the methods are shown in Table 1.

Table 1. Parameters of filtering methods

Filter	Parameter	Description
Multi resolution filter	σ_d	Weight control parameter in the spatial domain
	σ_r	Weight control parameter of in the intensity domain
	σ_n	noise standard deviation
	n	Block size
Cross-channel NLM filter	m	The size of the "search window"
	s	The size of "similarity window "
	h_0	global smoothing parameter which controls the amount of blurring introduced in the denoising process for the *Y* channel
	h_1	global smoothing parameter which controls the amount of blurring introduced in the denoising process for the *Cr* channel
	h_2	global smoothing parameter which controls the amount of blurring introduced in the denoising process for the *Cb* channel

At the stage of data transfer the coding of the *U1* grayscale image or the *U2* color image is performed. And the transmission it to the user by the communication channel.

On the transmission side, discrete information is read from the storage in the size of a standard block, the Walsh functions are calculated by numerical methods, after which the corresponding numbers of the Walsh functions are selected programmatically. Thereafter, the received Walsh function numbers are transmitted to the communication channel. At the receiving side, the corresponding Walsh function numbers are obtained, after that the Walsh functions are restored, and with the usual binary summation the original information is restored.

In the case of processing grayscale *X1* information technology works in one of six modes (Table 2).

Table 2. The modes of the information technology for filtering and storing digital images in the case of processing grayscale images *X1*

Filtering	Deblocking	Transmitting
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1

In the case of color image processing *Y2*, information technology operates in one of two modes (Table 3).

Table 3. The modes of operation of information technology for filtering and storing digital images in the case of processing color images *Y2*

Filtering	Transmitting
1	0
1	1

The final product of information technology is an improved image of *W1* or *W2*. That is, an image with better visual quality, and a greater signal/noise ratio than the original *X1* or *X2* images.

3. EXPERIMENTAL RESULTS

To demonstrate the effectiveness of the proposed IT we decide to compare the developed IT with existing analogs, which are used for the same purpose, by the example of a video surveillance system. The size of archive was chosen as an indicator of efficiency.

The comparison is based on the following methodology, which consists of the following stages:

1. Type definition of input video sequence.

2. Image filtration.

3. Lossy compression by codec.

4. Estimation of the compression coefficient.

5. Quality estimation of compressed images.

6. Reducing compression artifacts (reducing the blocking effect).

7. Quality estimation of obtained images.

At the first stage, we determine the type of input video sequence, which can be grayscale or color.

At the second stage for filtering the obtained video sequence:

a) video sequence is split into frames;

b) for each frame:

- in the case of 8-bit grayscale video sequences, a multi resolution bilateral filter is applied with appropriate parameter settings;
- in the case of a 24-bit full-color video sequence:
  - the image is transformed into color space *mYCrCb*;
  - cross-channel NLM image filter is performed;
  - the inverse transformation into the RGB color space is performed.

c) Composing video sequences from processed frames is performed.

The following codecs are used for video sequence compression:

- frame-by-frame (MJPEG);
- inter-frame (H.264, MPEG-4 (XVID)).

Compression parameters:

- «high quality»;
- «medium quality».

At the third stage we make a compression with the following compression ratio:

$$k = \frac{S_o}{S_c}, \tag{12}$$

where: k– the compression coefficient; S_o– the size of output data; S_c– the size of compressed data.

At the fourth stage, we estimate the quality of compressed video sequence. The quality is estimated by subjective criteria based on mean opinion score and by quantitative criteria– BIQI.

For subjective quality estimation, the MSU Perceptual Video Quality tool software is used and the SCACJ assessment method (Stimulus Comparison Adjectival Categorical Judgment)[20]. The evaluation results are stored in the file *.csv. As a result of the evaluation of all experts, the average subjective estimate of MOS is calculated:

$$MOS_k = \sum_{i=1}^{e\_num} \frac{mark_{i,k}}{e\_num} \quad (13)$$

where: k – the number of video sequences for which the mark is calculated; $mark_{i,k}$ – the mark given by the i-th expert of the k-th video sequence; e_num – general number of experts.

At the fifth stage, for quantitative estimation of video quality, we use the quality index BIQI. The values of the quality index BIQI range from 0 to 100 (0 is the best quality, 100 is the worst quality). The lower BIQI value means the better the image quality. To determine the BIQI we use "BIQI Software release".

At the sixth stage, to reduce the compression artifacts, we use deblocking method.

At the seventh stage, we estimate the quality of video sequence after using deblocking method. The quality is estimated by subjective criteria based on mean opinion score and by quantitative criteria – BIQI. For subjective quality estimation we use the MSU Perceptual Video Quality tool software and SAMVIQ assessment method (Subjective Assessment Method for Video Quality Assessment).

The proposed information technology was researched to reduce the video archive of the video surveillance system with different parameters (Table 4).

Table 4. Parameters for calculating the archive size

№	Numbers of cameras, pcs.	Complexity of scene	Resolution, pixels	Color depth, bit	Frame rate, frames/sec.	Codec	Number of recording hours per day	Number of recording days
1	2	Parking	1024 ×768	24	25	H.264	12	7
2	4	Building	800 ×600	24	25	MPEG-4 (XVID)	8	7

For image denoising we use cross-channel NLM filter with the following parameters: the size of the “search window” – 21 × 21 pixels; the size of the “similarity window” – 7 × 7 pixels, $h_0 = 10$, $h_1 = 60$, $h_2 = 80$. A comparison was made for the video sequence with the "high quality" (Table 5) and "medium quality" (Table 6) parameters.

Table 5. Comparative characteristics for various application software under compression with the “high quality” parameter

№	Characteristics	Without filtering	Application software			
			Noise Ninja	AKVIS Noise Buster	Neat Image	Proposed IT
1	The size of source file, Gb	240,5	180,5	198,2	187,7	169,3
2	The size of source file, Gb	144,2	90,7	103,6	105,8	80,3

Table 6. Comparative characteristics for various applications software under compression with the “medium quality” parameter

№	Characteristics	Without filtering	Application software			
			Noise Ninja	AKVIS Noise Buster	Neat Image	Proposed IT
1	The size of source file,Gb	210,2	125,01	140,2	134,6	118,6
2	The size of source file,Gb	121,9	69,2	77,9	79,6	61,7

The quality of the video sequences obtained after compression has been evaluated by subjective criteria based on mean opinion score. There were 50 experts involved who needed to compare the video sequence of 20 seconds without filtering and filtering various applications using the SCACJ scoring method. The averaged results are presented in Table 7 and Table 8.

Table 7. The results of quality assessment using the SCACJ method for a video sequence compressed with the MPEG-4 (XVID) codec with the “high quality” compression parameter

Rating / Software	"much worse"	"worse"	"slightly worse"	"unchanged"	"slightly better"	"better"	"much better"
Noise Ninja	0%	0%	6%	12%	44%	36%	2%
AKVIS Noise Buster	0%	0%	10%	14%	52%	24%	0%
Neat Image	0%	0%	10%	12%	50%	26%	2%
Proposed IT	0%	0%	6%	10%	46%	36%	2%

Table 8. The results of quality assessment using the SCACJ method for a video sequence compressed with the H.264 codec with the “high quality” compression parameter

Rating / Software	"much worse"	"worse"	"slightly worse"	"unchanged"	"slightly better"	"better"	"much better"
Noise Ninja	0%	0%	4%	14%	50%	30%	2%
AKVIS Noise Buster	0%	0%	8%	16%	54%	22%	0%
Neat Image	0%	0%	6%	14%	52%	28%	0%
Proposed IT	0%	0%	4%	10%	48%	36%	2%

For a quantitative estimation of quality, a quality indicator BIQI was used. The averaged results are presented in Table 9.

Table 9. The averaged results by the BIQI for video sequences compressed with the “high quality” parameter

№	Without filtering	Noise Ninja	AKVIS Noise Buster	Neat Image	Proposed IT
1	42,0338	33,6084	33,5092	33,7159	32,0434
2	42,9203	34,0279	34,4620	34,7364	33,4279

Similar quality studies have been conducted to evaluate video sequences compressed with the “medium quality” parameter. The averaged results are presented in Tables 10-12.

Table 10. The averaged results using the SCACJ method for a video sequence compressed with the MPEG-4 (XVID) codec with the “medium quality” parameter

Rating / Program	"much worse"	" worse"	"slightly worse"	"unchanged"	"slightly better"	"better"	"much better"
Noise Ninja	0%	4%	8%	12%	54%	20%	2%
AKVIS Noise Buster	0%	4%	6%	14%	56%	18%	2%
Neat Image	0%	2%	8%	12%	60%	14%	4%
Proposed IT	0%	2%	6%	10%	54%	26%	2%

Table 11. The averaged results using the SCACJ method for a video sequence compressed with the H.264 codec with the "medium quality" parameter

Rating / Program	"much worse"	"worse"	"slightly worse"	"unchanged"	"slightly better"	"better"	"much better"
Noise Ninja	0%	2%	4%	18%	52%	22%	2%
AKVIS Noise Buster	0%	4%	8%	16%	58%	14%	0%
Neat Image	0%	2%	8%	14%	58%	16%	2%
Proposed IT	0%	2%	4%	10%	56%	24%	4%

Table 12. The averaged results by the BIQI for video sequences compressed with the "medium quality" parameter

№	Without filtering	Noise Ninja	AKVIS Noise Buster	Neat Image	Proposed IT
1	56,4814	36,4538	39,5426	35,7557	33,9537
2	55,5579	36,1027	38,6021	35,4917	33,4732

The quality of the video sequence obtained after compression has been evaluated by the BIQI indicator and by the subjective criterion based on MOS. There were 50 experts involved who needed to compare the video sequence of 20 seconds without reducing the blocking effects and reducing the blocking effects by the SAMVIQ assessment method. The averaged results are presented in Table 13.

Table 13. The averaged results by BIQI and MOS for video sequences compressed with the "medium quality" parameter

№	Characteristics	Without deblocking	Application software			
			Jpeg Enhancer	UnJpeg	Happy Digital's JPEG Image Enhancer	Proposed IT
1	BIQI	56,5011	36,7917	39,4910	35,5339	34,2821
	MOS	51,54	65,58	63,74	61,92	68,52
2	BIQI	56,9760	36,6781	38,7995	35,5165	34,1924
	MOS	51,10	66,18	64,62	63,14	69,70

Analyzing the data obtained after comparison, we can conclude that the developed IT has allowed to reduce the archive size on average to 7% – 17% in comparison with similar software products, under compression by MPEG-4 codec (XVID) with the "high quality" compression parameter and to 5% – 18% in comparison with similar software products, under compressing by MPEG-4 (XVID) codec with the "medium quality" compression parameter, at maintaining image quality according to the indicator BIQI <40 and MOS, which corresponds to the "good quality" assessment.

The developed IT has allowed to reduce the archive size on average to 13% – 32% in comparison with similar software products under compression by the H.264 codec with the "high quality" parameter, and to 12% – 29%, in comparison with similar software products, under compression by the H.264 codec with the "medium quality" parameter at maintaining image quality according to the indicator BIQI <40 and MOS, which corresponds to the "good quality" assessment.

4. CONCLUSIONS

The important scientific and practical task of developing information technology for filtering and storing images obtained in low light conditions is solved. This allows saving memory resources for storing digital images by filtering noise and increasing the signal-to-noise ratio and visual quality of digital images by reducing the blocking effect.

The structure of information technology for filtering and storing images in the low light conditions, which includes input data, color models, image processing methods (filtering, compression, blocking effect reduction, coding and transmission), algorithms and software, was proposed. Depending on image type, task and result requirements the proposed information technology performs image processing with appropriate filtering methods and has the possibility of image quality enhancement and saving memory resources for storing digital images.

The experimental results are shown high efficiency of the proposed information technology by the example of saving memory resources in the video surveillance system with different parameters.

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