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# TECHNICAL SCIENCES

## ALGORITHMS FOR IMPROVING THE QUALITY OF FACIAL IMAGES

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**ABSTRACT**

Image quality has a great impact on the accuracy of system performance in face recognition based on facial image analysis. Therefore, it is necessary to properly organize the process of taking pictures and pre-processing them using a photo or video camera. Pre-processing of images allows for improved image quality. Therefore, this research work is dedicated to the research of face image quality enhancement algorithms, which have been studied mainly divided into two large groups known as spatial and frequency methods. Also, the main problems that arise in the development of personal identification systems based on the analysis of facial images and the requirements for human face rotation in the systems are presented.

**Keywords:** face image, pixel, Fourier transform, focal length, viewing angle, filter, brightness, contrast, perspective, recognition.

The main goal of improving the quality of images is to achieve results that are more suitable for use in a particular direction. For example, to recognize a person based on facial image analysis. The result of image processing is also an image. In this case, the quality of images is increased by applying pre-processing algorithms [1-11]. Image quality enhancement methods are divided into two large groups, known as spatial and frequency methods [12].

In spatial methods, an image is considered as a set of pixels in a plane and it relies on image processing. The frequency methods are based on the transformation of features formed by the Fourier transformation of the image (Butterworth, Gaussian filters are ideal filters for high and low frequencies). To date, there is no general theory of image quality improvement [12].

The main problems that arise in the development of personal identification systems based on facial image analysis are as follows:

a) recording conditions: distance from the object to the camera, camera location, perspective, lighting;

b) digitization parameters: number of pixels, brightness level value, contrast, intensity (color saturation level);

s) interruptions occurring at the stage of image capture and image digitization;

d) emotional state of a person (facial expression - neutral, cheerful);

e) Obstructions in the parts of the face image: changes in the face (wrinkles, spots) due to certain objects, hair, beard, mustache, glasses, aging, and other reasons.

***Camera location.*** The location and orientation of the camera lens is one of the most important parameters in successful identification, and it allows to photograph of the person at the right angle and in the required lighting.

Currently, millions of surveillance cameras are being installed in the world every year. When studying the details of an event, the quality of the video footage is sometimes not enough to recognize and identify the objects in it, for example, a person, an item, or a car license plate. Eliminating this problem leads to the waste of a large amount of resources and tools [13]. If the surveillance camera system is required to identify and recognize people, objects, or figures, it is necessary to take into account factors such as the level of illumination, camera location, and movement, in addition to the sufficient number of pixels in the image [14].

***Select a tracking location.*** The most important recommendations that need to be taken into account when installing the camera are as follows:

– emergence of leaves on trees as a result of seasonal changes;

– appearance of extraneous lighting sources;

– the level of illumination in a certain part of the season and area;

– reduction of image quality due to reflection of light from glass, building, or water;

– if the camera is used for personal identification, then it should be installed at the height of the head of a medium-sized person [15].

The calculation of the viewing angle of the video camera is carried out as in Figure 1, that is:

$$\alpha = 2arctg(d/2F);$$

where α is the viewing angle of the lens, d is the size of the light-sensitive element, and F is the effective focal length of the lens.

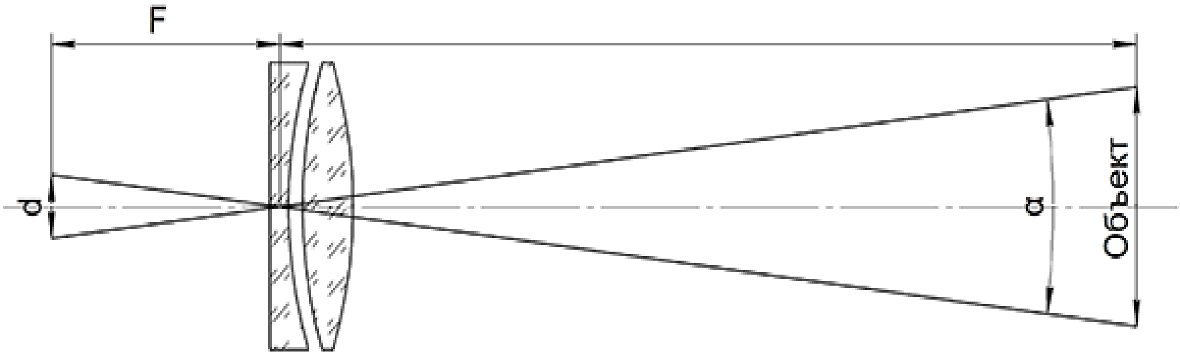



*Figure 1. Video camera viewing angle*

When choosing the focal length of the lens, it is necessary to take into account that the viewing angle of the human eye is 36 degrees horizontally, and it corresponds to a focal length of approximately 6.9 mm [16]. The relationship between the distance to the object, the focal length, and the viewing angle is presented in Table 1.

Table 1

The distance to the object depends on the focal length and the viewing angle

| Focal length | 2,8 mm | 3,6 mm | 6 mm | 8 mm | 12 mm | 16 mm |
|---|---|---|---|---|---|---|
| Viewing angle | 86° | 72° | 48° | 30° | 25° | 17° |
| Distance to object | 0-5 m | 0-6 m | 5-10 m | 10-20 m | 25-35 m | 35-50 m |

If it is required to monitor the specified area with a minimum number of cameras, then it is recommended to use cameras with a small focal length. If it is required to identify and recognize details, paper money, car number plate, and person's face, then it is appropriate to use cameras with a large focal length [17].

Distances are usually calculated based on European regulatory requirements for CCTV:

– number of linear pixels for object detection - 20 pixels/m;

– number of linear pixels for recognition - 100 pixels/m;

– number of linear pixels for identification - 250 pixels/m;

– the number of pixels in the video camera matrix should be 1080 (2Mp Full HD), 700, 560, 480, and 380 [17].

The table below shows the approximate distances for cameras in identification and recognition.

Table 2

Approximate distances for cameras

| Focal length (mm) | Identification distance (m) | Recognition distance (m) | Detection distance (m) |
|---|---|---|---|
| 2,8 | 1,86 | 4,66 | 23,33 |
| 3,3 | 2,20 | 5,50 | 27,50 |
| 3,6 | 2,40 | 6,00 | 30,00 |
| 4,2 | 2,80 | 7,00 | 35,00 |
| 6 | 4,00 | 10,00 | 50,00 |
| 8 | 5,33 | 13,33 | 66,66 |
| 9 | 6,00 | 15,00 | 75,00 |
| 12 | 8,00 | 20,00 | 100,00 |
| 22 | 14,66 | 36,66 | 183,33 |
| 50 | 33,33 | 83,33 | 416,67 |

***Angle.*** The position of the human face in the image, that is, its location in space, is called perspective. This problem is solved by such approaches as geometric substitutions, twists, and rendering in 3D. However, despite the existence of such approaches, this problem remains relevant today [18]. Some examples of the positioning of the human face to the camera are shown in the figure below.

*Figure 2. Examples of human face positioning in relation to the camera*

The solution to this problem is implemented in many systems based on the initial requirements and the boundary conditions for the deviation angles of the human face relative to the spatial axes. For example, the turning angle of the human face must not exceed 30 degrees in the horizontal axis and 15 degrees in the vertical axis. Such information is reflected in the table below.

Table 3

Requirements for human face rotation in systems

| № | Name | Angle of deviation |
|---|---|---|
| 1. | NeoFace Suit | Horizontal $30^0$, Vertical $15^0$ |
| 2. | Verilook Surveillance SDK | Horizontal $45^0$, Vertical $45^0$ |
| 3. | PittPatt | Horizontal $18^0$, Vertical $36^0$ |
| 4. | Cognitec FaceVACS SDK | Horizontal $15^0$, Vertical $15^0$ |
| 5. | Sure Match 3D | Horizontal $90^0$, Vertical $90^0$ |

***Illumination.*** The effect of the level of illumination on the identification of persons and objects is very large. Shadows, high contrast, and misdirected light complicate the process of identification and recognition. For example, a lens with a focal length of 50 mm is required for about 80 pixels to correspond to the face of a person at a distance of 15-20 m. However, if the illuminance is 100-150 lux, reliable identification is not possible even with this level of resolution, and illuminance at this value is typical for subway stations and corridors of office buildings.

Additional features in cameras also perform better when properly directed additional lighting is available, as can be seen in Figure 2.4. 300-500 lux illumination is recommended for personal identification, and 150 lux illumination is required for identification of numbers and symbols [18].

a) b) c) d)

*Figure 3.*
*The effect of illumination on the ability to identify: a) the image was taken at an illumination of 1600 lk and properly directed light; b) illumination is 350 lk, but the light is not directed correctly; c) the image was taken at 7 lk illumination and properly directed light; d) image taken at 1.5 lk illumination and properly directed light.*

In low-light conditions, the light-sensitive matrices of the camera create a significant level of interference, which negatively affects the image quality (Fig. 4). This creates various problems in identification. In any lighting situation, it is necessary to determine the best balance between interference, eclipses, and color contrast, but the better the lighting conditions, the easier it is to solve this problem [19, 20].

*Figure 4. Creative image*

***Digitization parameters and image sizes.*** The number of pixels in the image is one of the main factors that determine its quality. Therefore, it is necessary to take it into account when designing personal identification systems. In almost all face recognition systems, the minimum number of pixels required in the area of the image and the face in it is given in advance. For example, the requirements for the number of pixels in the AXIS system are presented in Table 4 [17].

Table 4

AXIS system resolution requirements

| Application requirements | Horizontal pixel border | Pixels/cm | Pixels/inch |
|---|---|---|---|
| In difficult conditions | 80 | 5 | 12,5 |
| In good condition | 40 | 2,5 | 6,3 |
| Recognition | 20 | 1,25 | 3,2 |
| Identify | 4 | 0,25 | 0,6 |

In some cases, you have to work with images with a lower resolution and lower quality than required. In this case, the use of special methods helps to obtain relatively improved resulting images.

***Super-resolution.*** This is the process of combining several small-sized images to create a high-resolution image, resulting in a somewhat higher-quality image (Figure 5).

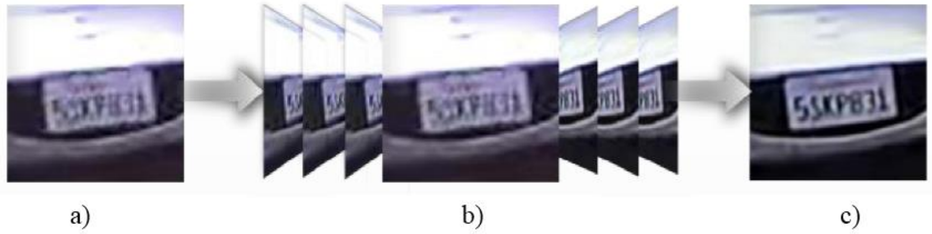



*Figure 5.*
*Super-resolution method: a) single low-quality frame; b) multiple shots of that view; c) reconstructed frame*

***Brightness value.*** In some cases, it is also necessary to work with images with insufficient brightness range and contrast in person recognition and image processing. Such defects in images significantly reduce the accuracy of personal recognition systems. Many algorithms have been developed to improve the visual appearance of images with insufficient brightness range and contrast. The most suitable algorithm and its parameters are selected depending on the image being processed. The most common brightness leveling algorithms are Auto Levels, gamma correction, Single-Scale Retinex, and Multi-Scale Retinex [21] algorithm and its modifications [22-23]. Examples of the results of using Single-Scale Retinex and Multi-Scale Retinex algorithms in images with uneven brightness distribution are shown in Figure 6.

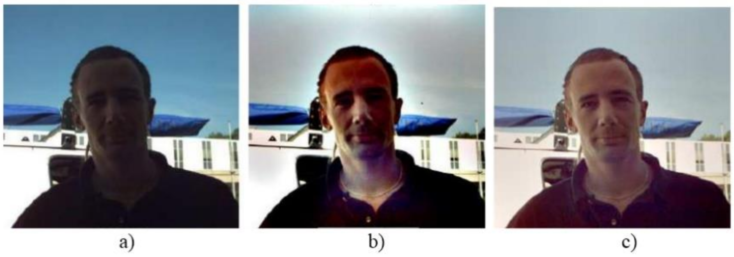



*Figure 6. a) original image; b) Single-scale Retinex; c) Multi-scale Retinex*

The Auto Levels algorithm allows to increase the contrast of the image due to the equalization of the intensity on all color channels, and it is based on the principle that "the darkest color in the image is black and the brightest color is white" [12]. In this algorithm, image enhancement is performed based on the following formula:

$$I_{new} = 255 * \frac{I-I_{min}}{I_{max}-I_{min}},$$

where $I_{new}$ is the new value of the pixel spectrum, $I$, $I_{max}$ and $I_{min}$ are the current, maximum and minimum values of the pixel spectrum in the given image.

The gamma-correction algorithm is based on the stepwise change in the intensity of the image pixels, and initially, its purpose was to correct the image for the correct display on the monitor. The following formula is used to correct the intensity [12]:

$$I_{new} = c * I^{\gamma}.$$

In this algorithm, the surrounding parts of the pixels are not taken into account, therefore, when there are strong dark and bright local areas in the image, algorithms of this category cannot provide quality improvement of images. In such cases, it is appropriate to use the Retinex algorithm [23] and its modifications.

The Multi-Scale Retinex (MSR) algorithm performs dynamic range compression while preserving local contrast in low-light and high-light areas of the image.

The classical multiscale MSR algorithm is a weighted sum of the single-scale SSR(Single-Scale Retinex) algorithm [19] for different scales. I-color channel one-dimensional output function Ri(x,y,s) is defined as follows [11].

$$R_i(x,y,\sigma) = log\frac{I_i(x,y)}{G(x,y,\sigma)*I_i(x,y)}.$$

where $I_i(x,y)$ is the input function of the i-color channel on $x$ and $y$ coordinates, $\sigma$ -scaling coefficient, the symbol * means the function convolution, $G(x,y,\sigma)$- Gaussian.

In this algorithm, the resulting output function $RM_i(x,y,\omega,\sigma)$ for $i$ -color channel is determined as follows [22].

$$RM_i(x,y,\omega,\sigma) = \sum_{n=1}^{N}\omega_n R_i(x,y,\sigma_n).$$

The results of the brightness smoothing algorithms are presented in Figure 7, from which it can be seen that the application of the MSR algorithm in the intensity channel gives a good result.

a) b) c) d)

*Figure 7. Results of brightness leveling algorithms: a) given image; b) Auto Levels; c) Multi-Scale Retinex; d) MSR on intensity channel*

For many images, the fixed values listed in Table 5 have been found to give the best results through experiments [19, 20].

Table 5

Multi-Scale Retinex algorithm constants

| Constanta | N | $\sigma_1$ | $\sigma_1$ | $\sigma_1$ | α | β | $\omega_n$ | G | b |
|---|---|---|---|---|---|---|---|---|---|
| Value | 3 | 15 | 80 | 250 | 125 | 46 | 1/3 | 192 | -30 |

***MSR algorithm modifications MSRCR (Color Restoration).*** This algorithm ends with a color recovery function. Experiments have shown that this algorithm reduces the intensity of colors when processing images with a dominant color. One of the best solutions to this problem is to apply the MSR algorithm to the intensity channel [24]. In this case, the original colors of the image are preserved, and the intensity of the channels is calculated by the following formula:

$$I = \frac{\sum_{j=1}^{S} I_j}{S},$$

where S is the color channel sequence number.

In this version of MSR, the value of $R_I$ is determined based on the following formula [25]:

$$R_{MSR_i} = \sum_{n=1}^{N}\omega_n R_{n_i} = \sum_{n=1}^{N}\omega_n[log\, I_i(x,y) - \log(F_n(x,y) * I_i(x,y))]$$

The final results are calculated for each color channel according to the following formula:

$$R_i = I_i\frac{R_I}{I}$$

The results of these algorithms are presented in Figure 8.

a) b) c)

*Figure 8. a) original image, b) MSRCR result c) MSR result*

Even in the ***MSRCP (chromaticity preservation)*** algorithm, the color balance is well preserved and the colors in the resulting image are the same as in the original image. Applying this algorithm to images with white lightning and correct color distribution gives a relatively good result. Even in cases where the MSRCR result reduces the color intensity, the MSRCP algorithm preserves the original colors of the image [25].

***Contrast.*** Contrast is a unitless quantity measured by the ratio of brightness values. There are different ways to calculate it [26], for example:

$$K = \frac{B_1 - B_2}{B_1}.$$

where $B_1$ is the brightness of the object in the image, $B_2$ is the brightness of the background.

In the Michelson method, the contrast is calculated as follows:

$$\gamma = \frac{B_{max} - B_{min}}{B_{max} + B_{min}}.$$

where $B_{max}$ and $B_{min}$ are the brightness levels of the brightest and darkest points in the image.

Image processing also uses the root mean square contrast value and is defined as:

$$K = \sqrt{\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(B_{ij} - \bar{B}\right)^2}.$$

***Histogram Equalization.*** In this case, the image brightness histogram is spanned and equalized, resulting in increased contrast. Software implementation of this algorithm is easy [12,27]. The result of stretching the gray image brightness histogram and changing the contrast by smoothing the histogram are shown in Figures 9 and 10, respectively.

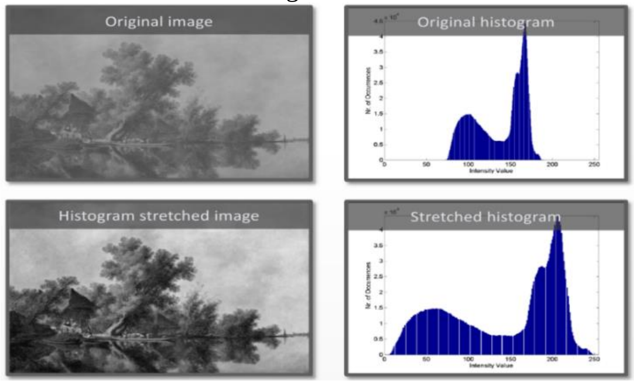



*Figure 9. Histogram stretching*


*Figure 10. Histogram equalization:*
*a) 16-level result; b) resulting histogram*

***CLAHE (Contrast Limited Adaptive Histogram Equalization).*** Although this algorithm is effective in processing medical images that do not fully utilize the brightness range, however, the appearance of artifacts indicates that this algorithm cannot be used in photo and video images. The results of gray image processing based on the CLAHE algorithm are presented in Figure 11.

*Figure 11. Result of CLAHE algorithm*

***MultiScale Retinex – MSR (Retinex Algorithm Family).*** The algorithm was proposed by the staff of the NASA Scientific Research Center, and it was developed on the basis of the single-scale retinex (SSR) algorithm. It is recommended to use this algorithm to improve the quality of images with uneven brightness distribution and increase the contrast. Bright circles in very bright and colorful images, darkening in black-and-white images, and the appearance of unnatural colors at the borders of color images are the disadvantages of this algorithm [19,28].

MSRCP (chromaticity preservation) and MSRCR (Color Restoration) algorithms, which are one of modifications of this algorithm, provide relatively good results (Figure 12).


*Figure 12. a) original image; b) MSRCR; c) MSRCP results*

***Interferences occur at the stage of image capture and image digitization.*** In low-light conditions, light-sensitive camera matrices create significant interference and reduce image quality. This, in turn, complicates solving the problem of identifying a person.

***Loss of nature.*** Natural light is a defect created in the image by the electronics and photosensor of the device, that is a digital camera, or a TV-video camera, due to the nature of the photon and the imperfection of the technology. There are impulse and Gaussian types of waveforms.

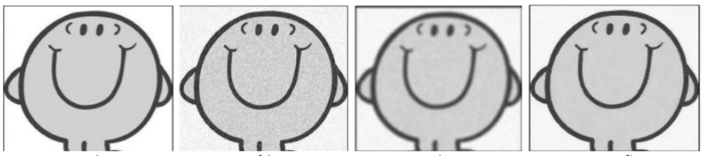
***Median filter.*** The median filter is very effective in removing impulse (salt and pepper) interference (Figure 13). The median filter replaces each pixel value with the median value based on an analysis of its surrounding neighbors. The median value is the value of the element in the middle of the array. The median filter is not effective for Gaussian interference.

a) b) c)

*Figure 13. a) image with salt-pepper interference; b) smoothing by filtering; c) median filter result*

***Anisotropic diffusion*** is a method aimed at reducing interference in the image without masking significant parts of the image [26].

This method was proposed by D. Gabor in 1965 and later by Peron and Malik in 1990. The method belongs to the class of non-linear and spatial methods, and it relies on the idea that the shear effect in each direction is inversely proportional to the gradient value in those directions. Anisotropic diffusion is an iterative process, the result of which can be compared with the result of Gaussian filter smoothing (Figure 14).



a) b) c) d)

*Figure 14. a) original image; b) interference image c) Gaussian smoothing; d) result of anisotropic diffusion*

The goal of the ***total variation regularization algorithm*** is to remove the interference when there are many types of interference in the image and to keep the image as close to its original state as possible. In this case, interference is eliminated while preserving the borders, which are one of the important details in the image. This algorithm is widely used in the processing of signals and digital images. This denoising technique is effective compared to methods such as linear smoothing, and median filtering, and is advantageous even in small signal-to-noise conditions. This algorithm was proposed by Rudin, Osher, and Fetami in 1992 and is described as follows [29].

In the algorithm, the output image $y$ is determined by taking the integral from the absolute gradient of the signal, i.e.:

$$V(y) = \sum_{n_1} \sum_{n_2} \sqrt{|y(n_1+1, n_2) - y(n_1, n_2)|^2 + |y(n_1, n_2+1) - y(n_1, n_2)|^2}\,.$$

In addition, the difference between incoming and outgoing images E $L_2$ is calculated according to the norm:

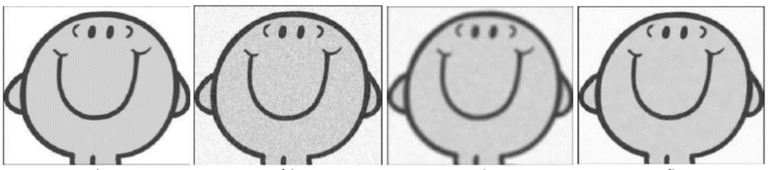
$$E(x, y) = \sum_{n_1, n_2} \left(x(n_1, n_2) - y(n_1, n_2)\right)^2 .$$

The following output function is used in the algorithm:

$$\hat{y} = \arg{}^{min}{}_{y}[E(x, y) + \lambda V(y)],$$

where $\lambda$ is the regularization parameter.

The result of the TVR algorithm can be compared with the result of smoothing using a Gaussian filter (Figure 15).



a) b) c) d)

*Figure 15. a) original image; b) interference image; c) smoothing result based on Gaussian filter; d) Total Variation regularization result.*

***Non-local means algorithm (Non-local means).*** Local smoothing methods are aimed at removing interference from the image and restoring its basic geometric shape, they do not preserve fine structure, details, and textures in the image. The high-frequency components of the image are lost along with the interference because they behave as interference in all functional aspects.

The nonlocal means algorithm tries to take advantage of the high degree of redundancy in any natural image [30]. Because a small window in a natural image will have several counterparts in this image. Filtering is done taking into account how similar the pixels around the pixel in question are. It is better than the Gaussian filter, that is, it gives a result close to the original state of the image. The main disadvantage of this algorithm is that it creates "method interference" similar to "white interference" during the process of character elimination. In recent years, as a result of further improvement of this algorithm, methods called deinterlacing (interaction) [31] and gaze interpolation [32] have been developed, which overcome the above drawback.

Below is a description of the discrete algorithm.

Suppose that the image Ω is given a certain area, p and q are two points belonging to the area. Then the filtering is done as follows:

$$u(p) = \frac{1}{C(p)} \sum_{q \in \Omega} v(q) f(p,q).$$

where $u(p)$ is the result of filtering point p, $v(q)$ is the unfiltered value of point q, $f(p,q)$ is the weighting function. In this case, the sum is calculated over $\forall_q \in \Omega$. The normalization factor $C(p)$ is calculated based on the following formula:

$$C(p) = \sum_{q \in \Omega} f(p,q).$$

The following expression is used for the Gaussian weighting function:

$$f(p,q) = e^{-\frac{|B(q)-B(p)|^2}{h^2}}$$

where $B(q) = \frac{1}{|R(p)|} \sum_{i \in R(p)} v(i)$, where $R(p) \subseteq \Omega$ is a square area of pixels surrounding pixel $p$, $|R(p)|$ and $R$ is the number of pixels in the region.

The result of removing mixed types of interference in the image based on the algorithm of non-local means is presented in Figure 16.

a) b) c)

*Figure 16. a) original image; b) interference image; c) result of non-local means algorithm*

## Conclusion

Research has been fully studied in the development of individual identification systems based on the analysis of the face. The methods and algorithms to solve these problems has been studied and comparative analysis. Image conditions, ie when the camera location, camera location, rhakordies, and the status of the image, the status of the image, the status of the image, the interface of colors, the intensity of colors, the intensity of colors, the intensity of colors, removing colors, and in the digitalization phase. Objectives in the parts of the facial images, for example, the research of methods and algorithms, as a result of identification and identification of a person, is the study of methods and algorithms and a comparative analysis. The acceptable ones were detected. In addition, based on identification systems based on the person's facial images, the image quality is of great importance in the accuracy of the system. When taking images through video surveillance and photo camera, it was noted that it was noted that it was necessary to pay special attention to:

– appearance of leaves on trees as a result of seasonal change;

– appearance of extraneous lighting sources;

– the level of illumination in a certain part of the season and area;

– reduction of image quality due to reflection of light from glass, building, or water;

– if the camera is used for personal identification, then it should be installed at the height of the head of a medium-sized person.

In case of insufficient illumination, it is recommended to use cameras with the possibility of infrared imaging and to take into account the requirements of European standards when choosing the correct camera focus distance, recognition and identification distances. Images with a low number of pixels can be enhanced using the super resolution method.

Multi-Scale Retinex algorithm and its modifications perform better than several other well-known algorithms when dealing with images with a small brightness range and insufficient contrast, and the Multi-Scale Retinex algorithm in the intensity channel is suitable for preprocessing face images with uneven distribution of illumination. is considered In this case, the brightness level, contrast and color intensity of the image can be better compared to the result of other algorithms. It is convenient to use histogram equalization method to improve contrast in grayscale face images and to implement these methods programmatically.

In face image denoising, the local means algorithm and its enhancements can perform better than other algorithms and filters in removing all types of noise and preserving fine structure, detail, and textures in the image.

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