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MACHINE LEARNING METHODS FOR IMPROVING THE QUALITY OF IMAGES FROM CCTV CAMERAS ON RAILWAY TRANSPORT

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ABSTRACT

The article has developed a methodology for changing the resolution (RS) of images obtained from CCTV cameras on railway transport. The research was carried out on the basis of the application of machine learning methods (MLM). Due to the implementation of this approach, it was possible to expand the functionality of the MLM. In particular, it was proposed to carry out the resampling process with the target frame information factor of the image. This coefficient is applicable for both increasing and decreasing of RS. This should provide a high quality of resampling and, at the same time, reduce the training time for neural-like structures (NLS).
There was developed a method of changing the RS using the NLS. This contributes to the high efficiency of resampling of the images obtained from CCTV cameras, according to the criterion based on PSNR. The proposed solutions are characterized by a reduction in the size of the computing resources that are required for such a procedure.
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Keywords: *Video Surveillance Systems, Railway Transport, Image Quality Improvement, Neural Networks*

1. INTRODUCTION

Technological approaches to the tasks of changing the resolution (RS) of images (including those based on various topologies of artificial neural networks - ANNs) obtained from CCTV cameras provide the use of various final coatings. In particular, on the basis of open sets. This gave researchers opportunities to create various vectors of features of an image or its fragment. Moreover, it became possible to characterize the elements of the topologies defined on the images. In feature spaces for images, there are vectors (possibly even with a large dimension) that characterize the image and make the use of machine learning methods (MLM) promising for processing these digital images [1], [2].

This article is devoted to the development of a methodology for changing the RS of an image based on MLM. The training is implemented on the basis of the neural-like structures (NLS) of a model, which allows performing geometric transformations. A feature of the developed methods is that they can be used both to reduce and to increase the resolution of images. The task of reducing the RS of an image based on ML has been solved for the first time. Also, the developed methodology does not require a large training sample, which is typical for most methods of this class.

2. LITERATURE REVIEW

Video surveillance systems for railway transport (RWT) are one of the key elements of modern systems that contribute to ensuring traffic safety on the railway. The quality of video surveillance systems directly affects the organization of transportation security. Intellectualization is one of the main requirements for modern video surveillance systems. Its essence lies in the fact that the system must not only record the video stream, but also carry out the specified target processing. The technical requirements for image processing are the functioning of video surveillance systems in automatic (or automated) real-time mode. In this case, the influence of the operator should be minimal.

One of the main tasks for the creation and development of automated control systems for railway transportation is the process automation for monitoring the movement of objects of the RWT rolling stock, including their identification, recognition of dangerous and emergency situations, etc. At the same time, one of the most important tasks of intelligent vision systems, which, in particular, are used in automated systems for video monitoring of the situation on RWT, is to improve the quality of digital images. Among the main tasks for ensuring the quality of images is the task of managing the resolution, in particular, its improvement. The latter is extremely important for the tasks of recognizing dangerous and emergency situations on RWT, and can help to prevent the occurrence of such situations, for example, by integrating decision support systems into the tasks of video monitoring for the operational management of the railway situation.

The development of computing tools opens up additional opportunities for the use of rather complex or resource-intensive methods for processing digital images in video surveillance systems based on intelligent technologies on dangerous sections of railway. This predetermines the possibility of solving the task of providing SR with the use of modern artificial intelligence tools to achieve a given level of quality in terms of both subjective and objective assessment, which is determined based on the quality indicators of digital images (peak signal-to-noise ratio (PSNR) and structural similarity index (SSIM)) [3], [4], [5].

The need to preserve (and in some cases - to improve) the content and textures, especially in cases of further intelligent analysis of images in technical vision and video surveillance systems, is an important task of the methods of providing SR. The complexity of this task is aggravated by the need to preserve the sharpness of images with a fluctuating intensity function, as well as to reduce artifacts and distortions that arise during the processing of the input image obtained from CCTV cameras.

Therefore, an urgent task is the development of SR methods for automated video surveillance systems that provide high-quality resampling results.

The task of super resolution (hereinafter - SR) is a task that is mainly formulated in an inverse form and is solved by a method, or a set of methods designed to preserve the finest details of an image, due to the processing of one input image or a set of input images of one scene (for example, obtained from CCTV cameras), due to the increase in the number of pixels per unit area in the original sample. Usually, the solution to this task is accompanied by the PR of the image with a increasing factor of more than 16.

Similar methods for the case of one image are based on reconstruction or training of recognition systems. Other methods, in case of a set of images of one scene, use additional informational content based on subpixel displacement on a non-integer pixel value in the middle of the set.

The term "super resolution" (SR) was firstly introduced by R. Gershberg [6] in 1974 in order to present his iterative method based on the Fourier transform. This made it possible to expand the segment of the final signal spectrum beyond its diffraction limit. An increase in the resolution (RS) of the signal occurs in accordance with an algorithm that reduces the error in the energy of the cut-off part of the signal. This method of processing in the frequency has laid the foundation for the development of numerous and varied methodologies for solving such tasks.

In general, the super resolution (SR) technology consists of two classes of methods [7], in particular: optical (OSR) and geometric (GSR) methods of SR. The first class (OSR) is made up of methods focused on hardware implementation. The second class (GSR) are methods, the algorithmic implementation of which is based on processing sets of the same types of images or their fragments, which are characterized by pixel or subpixel displacement.

Before considering the varieties of geometric methods of SR and their features, let us familiarize ourselves with the main hardware approaches to solving the task of increasing the RS of an image.

There are two main ways to increase the number of pixels on a capture device's sensor: 1) physically reduce the size of each pixel, 2) increase the size of the sensor itself.

In the first case, the amount of light available for absorption is reduced in a device, for example, a CCTV camera. This can cause the appearance of such a physical phenomenon as fractional noise.

The main disadvantage of the second method is the increase in the transmission time of the captured image to the device memory. Since modern digital devices, including CCTV cameras, impose a number of restrictions on the dimension of the image matrix, there is occurred a practical problem of detalization of the image or a certain object of attention in the picture using geometric methods.

An image increase for several times while preserving its information content is the main goal of many methods. Despite this, scaling results can vary significantly depending on the selected algorithms. In addition, they have a number of disadvantages, among which the largest is the appearance of artifacts that cause blurring in areas characterized by significant fluctuations in the values of the image intensity function.

In recent years, the number of methods for obtaining SR images has increased tremendously. The number of works has also increased in which different classifications of existing methods are presented according to various criteria: work in the frequency or spatial domain [7], based on the processing of one image [8, 9] or a set of images of one scene [10], [11], reconstruction method and etc.

The purpose of the SR images methods based on reconstruction technology is to restore image details due to interpolation of the input sample of low resolution while maintaining the sharpness of the image edges. There are many varieties of such algorithms.

A number of methods [12], [13], [15] are designed to remove or to reduce the occurrence of anti-aliasing artifacts. To do this, they use the so-called "primary sketches" - natural, basic elements of recognition [13] as a priori information in the operation of the algorithm.

3. PURPOSE OF THE ARTICLE

Development of a methodology for changing the image resolution obtained from CCTV cameras on railway transport by using machine learning methods.

4. METHODS AND MODELS

There is described the developed methodology for changing the RS of the image obtained from CCTV cameras, based on MLM, as a result of using the NLS model of geometric transformations (NLS MGTR) [12]. The use of this particular toolkit for our task is justified by the high speed of work in the training and application modes, as well as by the sufficient reliability of the training mode of the NLS MGTR of linear and nonlinear types [16], [17], [18].

The input data for the method will be a pair of images with a low and high RS. On the basis of these images, the training of the NLS MGTR is performed [14] (Fig. 1).

Let the image from the CCTV camera have a low RS (hereinafter LRS) and can be specified by a matrix I, with a dimension $l \times l, l \in N, l > 0$. In turn, a high-resolution image (HRS) is set by a matrix $I^{(m)}$, with a dimension $h \times h, h \in N, h > 0$. The LRS and HRS image matrices consist of the pixel intensity values.

Then:

$$I = \begin{pmatrix} c_{1,1} & \dots & c_{1,l} \\ \dots & \dots & \dots \\ c_{l,1} & \dots & c_{l,l} \end{pmatrix}, I^{(m)} = \begin{pmatrix} c^{(m)}_{1,1} & \dots & c^{(m)}_{1,h} \\ \dots & \dots & \dots \\ c^{(m)}_{h,1} & \dots & c^{(m)}_{h,h} \end{pmatrix}, \quad (1)$$

where $c_{i,j}, c^{(m)}_{i,j}$ – the value of the intensity function in a pixel that has the following coordinates in the image– (i, j) with LRS I and HRS $I^{(m)}$, respectively;

$m \in N, m > 0 -$ RS change factor;

$h = l \times m -$ a variable that will set the dimension of the matrix for the images with HRS $I^{(m)}$.

In course of the implementation of training technologies, images (with LRS and HRS) are divided into equal numbers of frames - $P_{i,j}, P^{(m)}_{i,j}$. Under the frame, see Fig. 1 a), we understand flat square areas characterized by the value of the image intensity function.

$$P_{i,j} = \begin{pmatrix} c_{k(i-1)+1,k(j-1)+1} & \dots & c_{k(i-1)+1,kj} \\ \dots & \dots & \dots \\ c_{ki,k(j-1)+1} & \dots & c_{ki,kj} \end{pmatrix}, \quad (2)$$

$$P^{(m)}_{i,j} = \begin{pmatrix} c^{(m)}_{mk(i-1)+1,mk(j-1)+1} & \dots & c^{(m)}_{mk(i-1)+1,mkj} \\ \dots & \dots & \dots \\ c^{(m)}_{mki,mk(j-1)+1} & \dots & c^{(m)}_{mki,mkj} \end{pmatrix}, i,j = \overline{1,n},$$

where $k \in N, k > 0 -$ variable that will set the frame dimension for images with LRS. Or $\dim(P_{i,j}) = k \times k$.

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a) Initial LRS Image And Sample Frames (Right)

b) HRS Image

Figure 1: A Pair Of Images Obtained From CCTV Cameras On The Railway Transport, And Used For Training NLS MGTR

The variable n that will determine the number of frames $P_{i,j}$ of the image I (with LRS) is defined as follows:

$$n = \frac{l}{k},\ n \in N,\ n > 0. \qquad (3)$$

There should be noted that k is multiple of l.

If we introduce the notation:

$$k^{(m)} = m \cdot k, \qquad (4)$$

then the frame dimension $P_{i,j}^{(m)}$ of the HRS image c will be $\dim\left(P_{i,j}^{(b)}\right) = k^{(m)} \times k^{(m)}$. Respectively, $k^{(m)} \in N, k^{(m)} > 0 -$ variable that will set the dimension of the frame $P_{i,j}^{(m)}$ of the image $I^{(m)}$.

It is obvious, that $\{\dim\{P_{i,j}\} = \dim\{P_{i,j}^{(m)}\}\} = n^2$.

Then, according to (4) and the definition of the value $h = l \times m$ the value $k^{(m)}$ is multiple of the value h.

Covering the image with frames will be disjunctive. Matrices (1) can be represented as sets of corresponding frames:

$$I = \begin{pmatrix} P_{1,1} & \dots & P_{1,n} \\ \dots & \dots & \dots \\ P_{n,1} & \dots & P_{n,n} \end{pmatrix},$$

$$I^{(m)} = \begin{pmatrix} P_{1,1}^{(m)} & \dots & P_{1,n}^{(m)} \\ \dots & \dots & \dots \\ P_{n,1}^{(m)} & \dots & P_{n,n}^{(m)} \end{pmatrix}. \qquad (5)$$

The solution to the task of increasing the RS of the image obtained from CCTV cameras is expressed by equality (4).

In case of solving the task of reducing the RS, the image should hold the following equality:

$$k = k^{(m)} \% m, \qquad (6)$$

where % – integer division.

One of the disadvantages of the NLS MGTR is the tabular presentation of input/output data [16], [17]. Therefore, in future, a pair of images used in the MLM procedures should be prepared as follows.

Each resulting frame $P_{i,j}$ from matrices I can be represented as a vector (see 7), and each frame $P_{i,j}^{(m)}$ from matrices $I^{(m)}$ as a vector (see 8)

$$A_w = \begin{pmatrix} c_{ki-k+1,kj-k+1}, c_{ki-k+1,kj}, \dots, \\ c_{ki,kj-k+1}, \dots, c_{ki,kj} \end{pmatrix}; \qquad (7)$$

$$A_w^{(m)} = \begin{pmatrix} c^{(m)}_{k^{(m)}i-k^{(m)}+1,k^{(m)}j-k^{(m)}+1}, \\ c^{(m)}_{k^{(m)}i-k^{(m)}+1,k^{(m)}j}, \dots, \\ c^{(m)}_{k^{(m)}i,k^{(m)}j-k^{(m)}+1}, \dots, c^{(m)}_{k^{(m)}i,k^{(m)}j} \end{pmatrix}; \qquad (8)$$

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where $w = j + \left(\left(l \cdot (i-1) \right) / k \right)$.

The sets A_w and $A_w^{(m)}$ have the same dimensionality.

$$\dim\{A_w\} = \dim\{A_w^{(m)}\} = n^2. \tag{9}$$

The next step is to form a training sample (TRS). TRS will consist of the corresponding sets $\{A_w\}$ and $\{A_w^{(m)}\}$.

It is implemented in the following way. The matrix for the training dataset (TDS) in course of implementing the solution to the yask of increasing the RS based on the NLS MGTR (for condition (2)), will be formed as follows:

$$M = \begin{pmatrix} A_1 & A_1^{(m)} \\ \ldots & \ldots \\ A_{n^2} & A_{n^2}^{(m)} \end{pmatrix}, \tag{10}$$

where the dimension of the set $\dim(A_1)$ determines the number of inputs of the NLS MGTR. In turn, the dimension of the set $\dim(A_1^{(m)})$ will determine the number of outputs of the NLS MGTR.

The TDS matrix M for the implementation of the solution to the task of increasing the RS of images based on the NLS MGTR, when performing (2), is formed as follows:

$$M = \begin{pmatrix} A_1^{(m)} & A_1 \\ \ldots & \ldots \\ A_{n^2}^{(m)} & A_{n^2} \end{pmatrix}, \tag{11}$$

where the dimension of the set $\dim(A_1^{(m)})$ determines the number of inputs of the NLS MGTR. Similarly, the dimension of the set $\dim(A_1)$ will determine the number of outputs for the NLS MGTR.

The generated TDS matrix M according to (10) or according to (11), that depends on the set task, will be submitted to the NLS MGTR.

Examples of topologies of NLS MGTR are shown on Figures 2 and 3.

Figure 2 shows the topology for the task of increasing the RS of the image. Figure 3 shows the topology for the task of reducing the RS of the image.

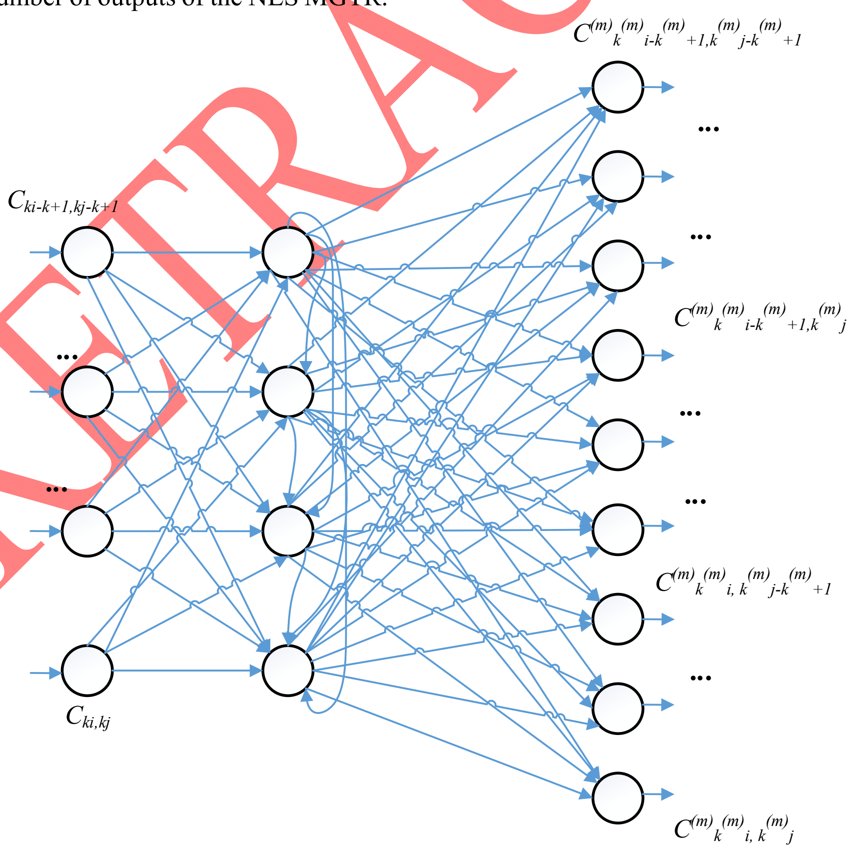

Figure 2: Scheme Of The NLS Topology For The Task Of Increasing The RS Of The Image

In order to generalize the description of the training technology in course of solving both tasks, the matrix can be represented as follows:

$$M = \begin{pmatrix} x_{1,1} & \dots & x_{1,k^2+(mk)^2} \\ \dots & \dots & \dots \\ x_{n^2,1} & \dots & x_{n^2,k^2+(mk)^2} \end{pmatrix}. \quad (12)$$

The training technology of the NLS MGTR is well described, for example, in [18]. This technology assumes the implementation, for example, by software, of such steps for changing the RS of the image.

In the first step, we select the base row from the training matrix M, for example, $x_b^{(1)}$, $x_b^{(1)} = \left(x_{b,1}^{(1)},\dots,x_{b,k^2+(mk)^2}^{(1)}\right)$. Moreover, the sum of the squares of the elements of this row should be maximum [18] – $1 \le b \le n^2$.

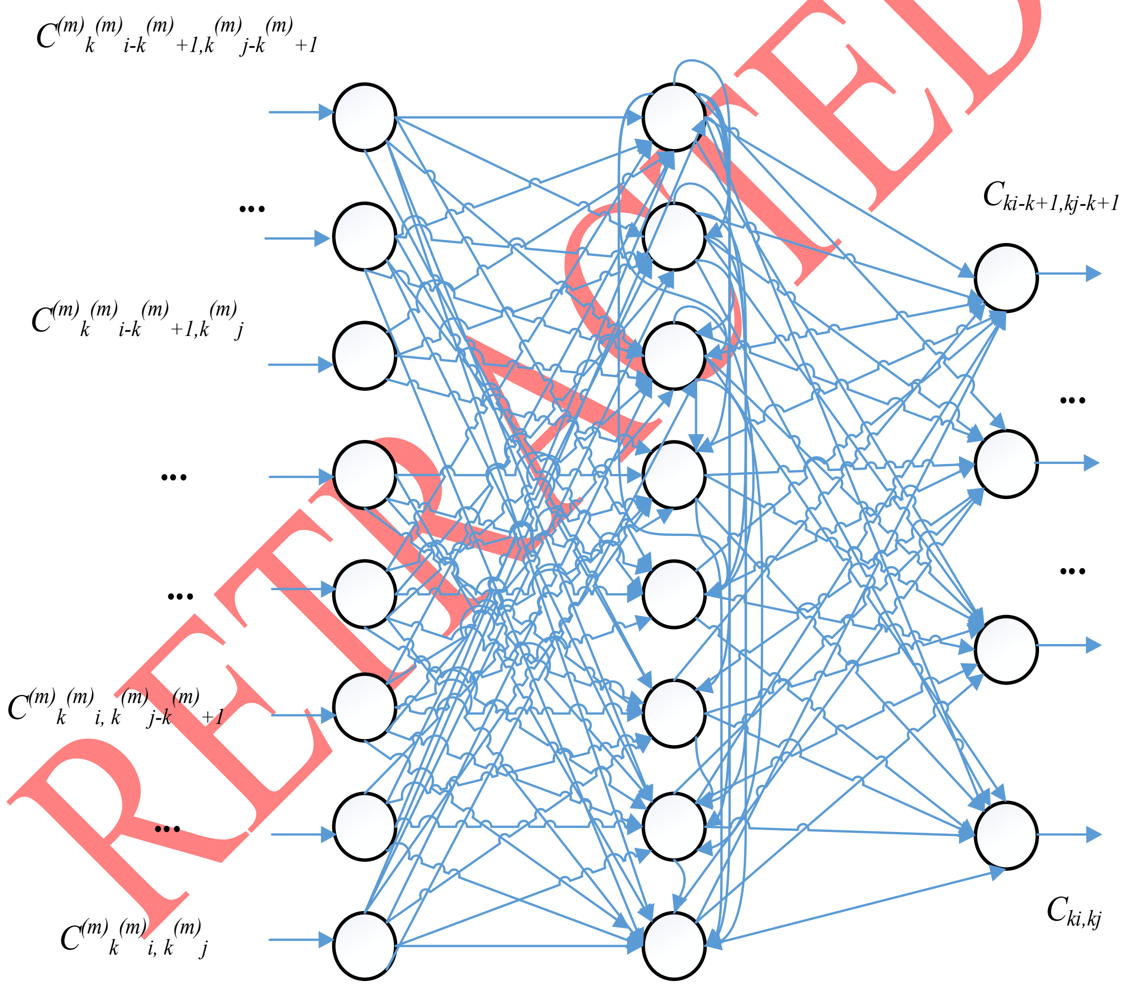

Figure 3: Scheme Of The NLS Topology For The Task Of Reducing The RS Of The Image

Each row vector of the initial matrix turns into $x_N^{(2)}$. This parameter is essentially the difference between the row vectors of the type $x_N^{(1)}$, $\left(x_N^{(1)} = \left(x_{N,r}^{(1)},\dots,x_{n^2,k^2+(mk)^2}^{(1)}\right)\right)$ from the matrix M, and the products by the coefficient $K_N^{(1)}$ of the selected rows of the type $x_b^{(1)}$, i.e .:

$$x_N^{(2)} = x_N^{(1)} - K_N^{(1)} \cdot x_b^{(1)}, \qquad (13)$$

where $1 \le N \le n^2$.

The value $K_N^{(1)}$ for each row is defined as the difference minimum (least squares criterion) [16]:

$$K_N^{(1)} = \frac{\sum_{r=1}^{k^2+(km)^2} \left(x_{N,r}^{(1)} \cdot x_{b,r}^{(1)}\right)}{\sum_{r=1}^{k^2+km} \left(x_{b,r}^{(1)}\right)^2}, \qquad (14)$$

where $z = k^2$ – in case (2) or $z = (mk)^2$ for case (2).

For each row $x_N^{(1)}$ of the matrix M calculate the additional parameter $P_N^{(1)}$. This parametr – the first component of the numerical characteristic of the implementation [17]:

$$P_N^{(1)} = \frac{\sum_{r=1}^{z} \left(x_{N,r}^{(1)} \cdot x_{b,r}^{(1)}\right)}{\sum_{r=1}^{z} \left(x_{b,r}^{(1)}\right)^2}. \qquad (15)$$

Coefficient $K_N^{(1)*}$ is defined as a function $F^{(1)}$ from the parametr $P_N^{(1)}$ [18]:

$$K_N^{(1)*} = F^{(1)}\left(P_N^{(1)}\right). \qquad (16)$$

The interpolating dependence (2) for the rows of the training matrix is reproduced in cases when the methodical error is zero [17]. Implementations for the rows M are approximate.

Next, we select a row $x_b^{(2)}$ from the training matrix M. Moreover, the sum of the squares of the elements $x_b^{(2)}$ will be maximum. The value of the elements $x_b^{(2)}$ is calculated as follows [16], [17]:

$$x_b^{(2)} = x_b^{(1)} - K_N^{(1)*} \cdot x_b^{(1)}. \qquad (17)$$

If, for example, we consider the $q-$th step of calculations, then we get:

$$x_N^{(q+1)} = x_N^{(q)} - K_N^{(q)*} \cdot x_b^{(q)}; \qquad (18)$$

$$K_N^{(q)*} = F^{(q)} \cdot \left(K_N^{(q)}\right); \qquad (19)$$

$$P_N^{(q)} = \frac{\sum_{r=1}^{z} \left(x_{N,r}^{(q)} \cdot x_{b,r}^{(q)}\right)}{\sum_{r=1}^{z} \left(x_{b,r}^{(q)}\right)^2}; \qquad (20)$$

$$x_b^{(q+1)} = x_b^{(q)} - K_N^{(q)*} \cdot x_b^{(q)}, \qquad (21)$$

where $q = \overline{1, k^2 + (km)^2}$.

Then, based on the latest calculations, the initial matrix M will take the following form, taking into account that at dividing into frames not all frames will be equally informative for machine learning procedures:

$$M = \sum_{q=1}^{k^2+(mk)^2} K_N^{(q)^*} \cdot x_N^{(q)} \cdot \psi, \qquad (22)$$

where $\psi -$ frame information factor (FIF). (For example, when processing frames that correspond to the background in images 1 with LRS and HRS, the background RS value is not so important. Therefore, it can be assumed that the value ψ will be 0,8-0,9. If the frame corresponds to an important part of the image, then the value $\psi = 1$.

The use of the frame information coefficient (FIF) in equation (22) makes it possible to reduce the computational resources that are directed to processing frames that are not significant for the general picture of frames, and, consequently, to reduce the training time, which will be further shown in course of experiments on training the system for increasing the RS of images.

Based on the results of the application of the MLM, which are based on the algorithmization of equations (18) - (22), it is possible to determine the vectors $x_N^{(q)}$, as well as the values of the function $F^{(q)}$. These parameters ($x_N^{(q)}$ and $F^{(q)}$) will be transmitted to the NLS MGTR.

In case of a software implementation of this approach, it is possible to achieve the features of non-iteration of the computational process, which, in turn, will provide a higher speed of its operation, which is especially important for the budget segment of CCTV cameras used on railway transport and transmitting images to control points or servers in on-line mode.

Then, in case of algorithmization of the model, presented above, the matrix M_t is supplied to the input of NLS MGTR where $M_t = \begin{pmatrix} A_1 \\ \dots \\ A_{n^2} \end{pmatrix}$, for the task of increasing the RS and

$M_t = \begin{pmatrix} A_1^{(m)} \\ \dots \\ A_{n^2}^{(m)} \end{pmatrix}$, the task of reducing the RS.

If we generalize both of the above tasks, then the matrix M_t can be presented in the following way:

$$M_t = \begin{pmatrix} x_{1,1} & \dots & x_{1,z} \\ \dots & \dots & \dots \\ x_{n^2,1} & \dots & x_{n^2,z} \end{pmatrix}. \quad (23)$$

where $z = k^2$ – in case of increasing the RS, $z = (mk)^2$ – in case of reducing the RS.

In accordance with the works [16], [17], as well as with the introduced new coefficient (FIF), which takes into account the information content of the image frames used in the MLM, in the process of using the NLS MGTR it is necessary to programmatically implement an algorithm that will perform the following operations:

1) if the input components of the vector $x_N^{(q)}$ are given (we take their values from M_t), then we calculate the value $P_N^{(1)}$ by formula (15);

2) by the formula (2) we find the values $K_N^{(1)}$;

3) for the value $q = 1$ by formula (16), we find the first transformation of the input vector $x_N^{(q)}$;

4) using equations (18) - (20) we will sequentially transform the q values until the achievement $q = \overline{1, k^2}$.. The main goal of all the above operations will be to find values from the set $\left\{K_N^{(1)^*}, K_N^{(2)^*}, \dots, K_N^{(q_{\max})^*}\right\}$;

5) using formula (22), we calculate all the components of M_t;

6) new matrices will be the final images that contain frames with HRS or LRS, respectively (24).

In fact, at the final step of the software implementation of this model, there is performed a procedure for collection of matrices generated by the NLS MGTR into the resulting images.

$$I_{res} = \begin{pmatrix} P_{1,1} & \dots & P_{1,n} \\ \dots & \dots & \dots \\ P_{n,1} & \dots & P_{n,n} \end{pmatrix},$$

$$I_{res}^{(m)} = \begin{pmatrix} P_{1,1}^{(m)} & \dots & P_{1,n}^{(m)} \\ \dots & \dots & \dots \\ P_{n,1}^{(m)} & \dots & P_{n,n}^{(m)} \end{pmatrix}, \quad (24)$$

where I_{res}, $I_{res}^{(m)}$ – the resulting images with HRS and LRS, respectively.

The number of vectors for data used during training directly depends on the size of the frames $\left(k \times k = \dim\left(P_{i,j}\right)\right)$ and $\left(k^{(m)} \times k^{(m)} = \dim\left(P_{i,j}^{(m)}\right)\right)$ the pair of images that form it, see table 2). The dimension of training samples using the ANN toolkit, as shown in [16], plays an important role.

Therefore, in order to study the effect of changing the sizes $P_{i,j}$ and corresponding $P_{i,j}^{(m)}$ (with different m) on the quality indicators of the HRS images, a number of experimental studies were carried out within the framework of this chapter of the work.

Parameters of NLS MGTR in accordance with the figure 1 a) are taken as follows: 1) the number of inputs $\dim\left(P_{i,j}\right)$ was 1; 2) the number of neurons in the hidden layer was $\dim\left(P_{i,j}^{(m)}\right)$; 3) $m = 2,3,4$.

The histograms that characterize the changes in the values of the peak signal-to-noise ratio for the HRS images used in the tests from the Table 1 in relation to the change $\dim\left(P_{i,j}\right)$ with the coefficient $m = 3$ are shown on Figure 4.

As can be seen from the histograms on Figure 4, the best results for the test sample (see Table 1) for all indicators were obtained for images with frame dimensions $\dim\left(P_{i,j}\right) = 36$ (Row 4). Slightly worse indicators has the row 5 - $\dim\left(P_{i,j}\right) = 49$. Further increase in this indicator leads to distortion of the test images of increased RS (Fig. 5). The results of increasing the RS of the images with $k \leq 4$ are satisfactory.

However, among the artifacts that arise in the process of resampling, the presence of visible frame boundaries significantly reduces the quality of images already at the stage of visual estimation.

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Table 1: Images Obtained From CCTV Cameras And Used For Training NLS MGTR

Test image number	Image	Test image number	Image
1		2	
3		4	
5		6	
7		8	
9		10	

In the case of an increase of RS starting from $m \leq 4$, it is recommended to increase the RS step by step, starting from $m = 2,3$ and up to the target factor of increasing the RS of the image, which, in fact, is determined by a specific technical task.

In the practical implementation of the described method, when forming the size of the frames of training samples for the values of the coefficients of increasing the RS of RWT $m \leq 4$, it is possible to choose pairs of frames with dimensions $\dim\left(P_{i,j}\right)=36$. The value $\dim\left(P_{i,j}^{(m)}\right)$ can be determined by calculation. The dimension of this pair of frames will determine the inputs and outputs of the NLS MGTR for the tasks of increasing the RS of images received from the CCTV cameras of the RWT.

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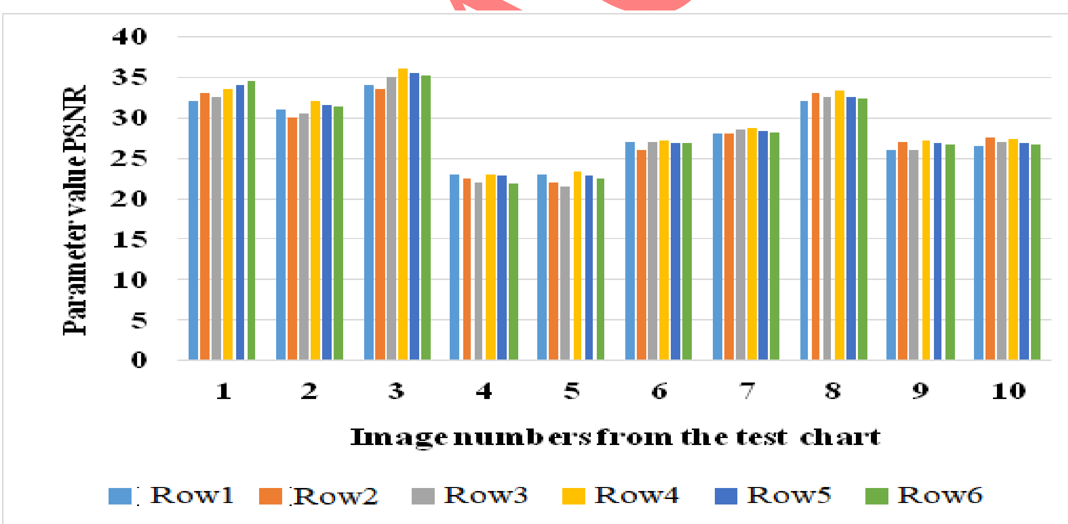
Table 2: Parameters $\dim(P_{i,j})$ *And* $\dim(P_{i,j}^{(m)})$ *For The Formation Of a Sample That Participates In MO*

Increasing factor	RS of the initial image	$\dim(P_{i,j})$	RS of the resulting image	$\dim(P_{i,j}^{(m)})$	The number of frames in the sample that participates in training
2	252×252	2×2	504×504	4×4	15876
		3×3		6×6	7056
		4×4		8×8	3969
		6×6		12×12	1754
		7×7		14×14	1296
3	168×168	2×2	504×504	6×6	7076
		3×3		9×9	3136
		4×4		12×12	1764
		6×6		18×18	784
		7×7		21×21	576
		8×8		24×24	441
4	126×126	2×2	504×504	8×8	3969
		3×3		12×12	1764
		6×6		24×24	441
		7×7		28×28	324



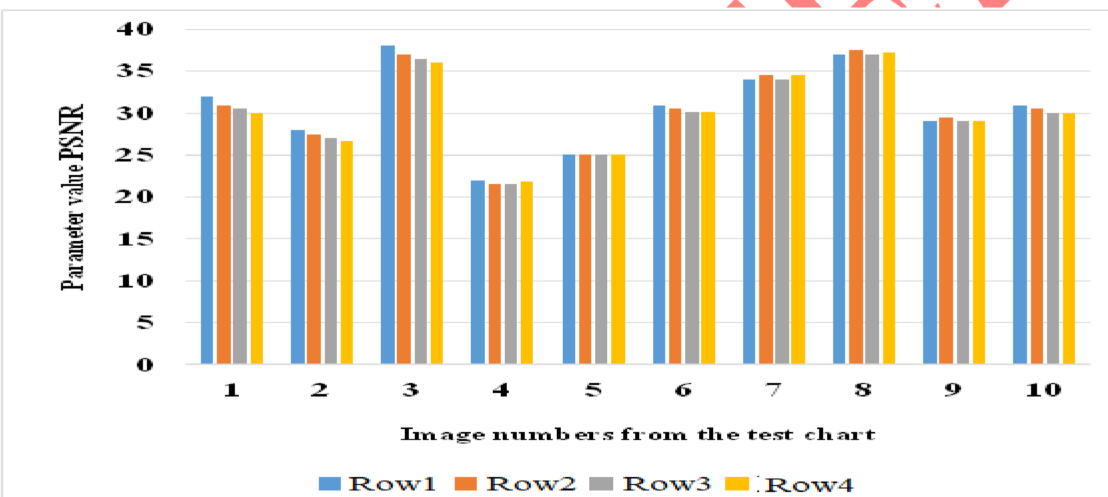
The values $\dim(P_{i,j})$*: row 1-4; row 2-9; row 3-16; row 4-36; row 5-49; row 6-64.*

Figure 4: Histograms Describing The Effect Of Resizing Of The Frame $\dim(P_{i,j})$ *On The Peak Signal-To-Noise Ratio (PSNR) For Test Images Of The Increased RS* $m = 3$

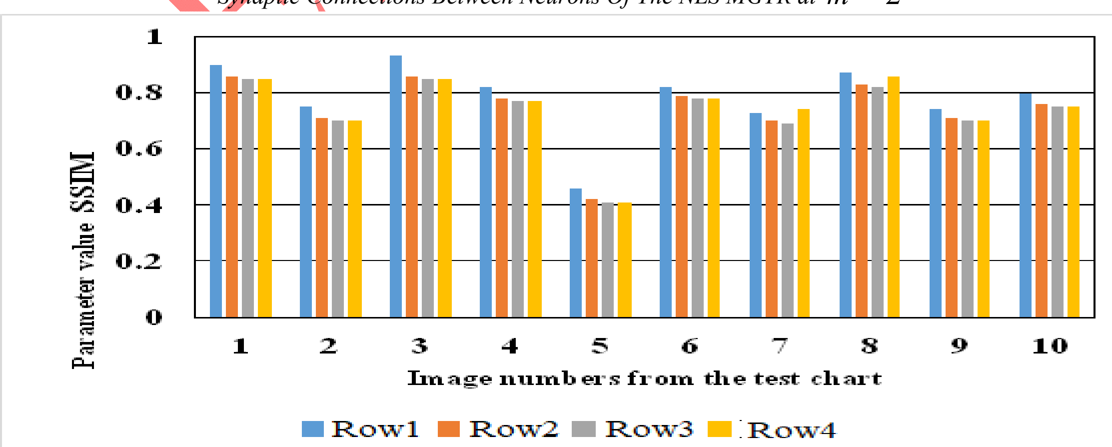
In course of studying the methodology for changing the RS of the images based on MLM, there were also carried out a series of tests aimed at studying the work of the NLS MGTR in solving the tasks of changing the RS and the effect on the result of the degree of nonlinearity of synaptic connections between neurons. In course of this series of tests, such a value of the degree of nonlinearity of synapses was determined, at which sufficient quality of the resulting image would be provided for a small amount of expended (allocated) computing resources for the operation of the NLS MGTR [1-4]. This formulation of the task is quite relevant for the real operating conditions of video surveillance systems on railway transport, which often do not have high technical parameters of computer technology for such tasks. The value of the degree of nonlinearity of synapses will be determined by the order of the polynomial. The corresponding experiments were as follows. Parameters of NLS MGTR for the Fig. 1 a) are taken as follows: the number of inputs $\dim\left(P_{i,j}\right)=36$, hidden layers - 1, the number of neurons in the hidden layer was 36. The increase of the RS is equal to $m=2$. The number of outputs of NLS MGTR is $\dim\left(P_{i,j}^{(m)}\right)=144$. The operation of the modified method of increasing the RS was carried out using test samples shown on the figures in Table 1. Figure 5 shows the results of this test series of experiments.

Figure 6 shows the graphs characterizing the change in the dynamics of the values of the structural similarity index ($SSIM$), if the degree of nonlinearity of synapses increases.

PSNR values, which were calculated for the images used in course of training (see Table 1, images No.1–4, 6, 9, 10 with increased RS), with an increase in the degree of nonlinearity of synaptic connections, showed a pronounced tendency to decrease in these tests. For the images (No. 5, 7, 8, see Table 1), the linear value of the degree of nonlinearity of synapses does not provide the best result (Fig. 6).



The degree of nonlinearity of synaptic connections: row 1-1; row 2-2; row 3-2; row 4-4.
Figure 5: Histograms Describing The Changes In The PSNR Metric, Changing The Degree Of Nonlinearity Of Synaptic Connections Between Neurons Of The NLS MGTR at $m=2$



The degree of nonlinearity of synaptic connections: row 1-1; row 2-2; row 3-2; row 4-4
Figure 6: Histograms That Characterize The Change In The Dynamics Of The Values Of The Structural Similarity Index ($SSIM$ *), If The Degree Of Nonlinearity Of Synapses Increases*

Therefore, summarizing the results of the experiments, it can be argued that the use of nonlinear synaptic connections between neurons does not confirm the improvement in the results of image resampling. This is a consequence of an obvious increase in the complexity of the network, and, therefore, negatively affects the deterioration of its properties.

It is also obvious that the introduction of nonlinearities significantly increases the consumption of computing resources spent on processing images from CCTV cameras. Based on the above, we can talk about the inexpediency of increasing this parameter, since the solution to the task is fully satisfied with the linear value of synaptic connections between neurons.

The method described in this clause (taking into account its modification by implementing the frame information factor) aimed at changing the RS of images based on the use of the NLS MGTR provides for two stages of its use in image processing. These are, respectively: 1) training; 2) application.

However, for example, solving the tasks of changing the RS of a set of images of the same type (which fits perfectly into the sets of images obtained from CCTV cameras of railway transport) makes it impractical to use the training stage for each sample.

Therefore, the trained NLS MGTR on one or three samples from the set can be used to change the RS of other images from the set. The operation in the mode of using the NLS MGTR is approximately 2–3 times faster than the training modes described in [16], [17]. However, the mode of application is preceded by preprocessing of images with LRS based on the expressions (2) - (11) given in the section. This imposes a number of restrictions on the use of the method for solving a number of practical tasks, for example, when the task is to increase the RS "on the fly" in the online mode. Therefore, there is a need to increase the speed of the method, in particular, by reducing the preprocessing procedures for the initial images obtained directly from CCTV cameras on the RWT.

Based on the research discussed in the first section of the dissertation, as well as in this section of the work on the influence of the degree of nonlinearity of synaptic connections on the quality of the initial images, we can state the following. The increase in the degree of nonlinearity of synapses does not impose additional problems on the quality of the initial sample. The deviations of the values of the PSNR and SSIM metrics for the images in test experiments are not large. This predetermined the possibility of using the NLS MGTR to solve the task. However, an increase in the degree of nonlinearity of synapses will significantly increase the consumed computational resources during the operation of the method.

Taking this into account, that in the practical software implementation of the procedure for changing the RS of the image, we should focus on the linear component of synaptic connections. This will make it possible to avoid constant use of the NLS application mode, in particular, when changing the RS of sets of images of the same type. In the next section of the dissertation, there is considered the application of the linear structure of the NLS MGTR, including linear neuron activation functions and linear synaptic connections. This will make it possible to apply the principles of linear superposition and to pass from the initial (Fig. 2, 3) to the equivalent schemes of the NLS MGTR. The equivalence process was considered in [16], [17] and allows to ensure the repetition of training algorithms, based on obtaining a matrix operator for the coefficients of synaptic connections weights of the NLS MGTR with many outputs. Its application will ensure the implementation of the procedure for resampling of images obtained from CCTV cameras of RWT, without using the NLS MGTR at the stage of application. In addition, matrix operators can reduce the running time of the image resampling method based on the training when processing a set of images.

5. CONCLUSIONS

There was proposed a methodology for changing the Rs of the images based on the use of MLM. Due to the implementation of this approach, it was possible to expand the functionality of the MLM. In particular, for the first time it is proposed to carry out the process of resampling with the target frame information factor of an image. This factor is applicable for both increasing and decreasing of the RS. This should ensure high quality resampling and at the same time to reduce the training time for the NLMS.

There was developed a method of changing the RS using the NLS MGTR. This contributes to the high efficiency of resampling of the images obtained from CCTV cameras, according to the criterion based on PSNR. The proposed solutions are characterized by a reduction in the size of the computing resources that are required for such a procedure.

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