**Journal of Theoretical and Applied Information Technology**
31st March 2021. Vol.99. No 6


ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

# DEVELOPMENT OF METHODS FOR CHANGING THE RESOLUTION OF IMAGES OBTAINED FROM SMART CITY CCTV CAMERAS BASED ON ALGEBRAIC CHARACTERISTICS

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**ABSTRACT**

The article proposes an improved method for increasing the resolution (RS) of images obtained from Smart City CCTV cameras or other video monitoring object for the case of one image based on the Moore-Penrose pseudo-inverse matrix (degenerate matrix operator of relative symmetric convergence measures). Due to this, it was possible to identify characteristics that can be used both for solving the problem of increasing the RS and for other tasks of intelligent image analysis in video monitoring systems. The modified method based on the pseudo-inverse degenerate matrix operator of relative symmetric convergence measures provides high efficiency of oversampling according to the criterion based on PSNR. Moreover, the modified method is characterized by the reduction of artifacts inherent in various types of interpolation when used in the tasks of image oversampling. A new method for increasing the RS of an image for the case of two images is proposed on the basis of combined use of the crossing-over operation and the pseudo-inverse degenerate matrix operator of divergences. The use of this operator in case of two images significantly increases the quality of oversampling and minimizes computational costs in practical implementations of algorithms for increasing the RS of an image in video monitoring systems.

**Keywords:** *Video Surveillance, Oversampling, Image Processing*

## 1. INTRODUCTION

The program for the transition of the world's leading states to the digital economy also provides the development of modern IT and Smart technologies [1-4]. One of the directions of Smart City development is the integration of existing video surveillance systems into the Smart City security circuits.

As a rule, the implementation of the operational goals of the Safe City direction using IT services is provided as follows. In all public places, video surveillance systems are being created for the territories and objects of the city with the ability to perform search tasks in the array of information received from CCTV cameras and for its analysis according to specified criteria. However, in this case, inevitably, in parallel, there is a task associated with improving the quality of the obtained data (images)

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

array for subsequent analysis. And one of these tasks is the task of increasing the resolution of images, for example, in situations where it is necessary to identify violators of public order, intruders, etc. or to recognize the registration numbers of vehicles that have violated the traffic rules. At the same time, within the framework of the implementation of certain investment strategies in Smart City technologies [5-9] funds are not always provided for video surveillance systems with high technical characteristics, because most of these systems are intended primarily for general monitoring of the situation in surveillance areas without the possibility of significant improvement the quality of the resulting image. All of the above mentioned has determined the relevance of our research, which is aimed at developing methods for increasing or decreasing the resolution of images obtained from CCTV cameras.

A prerequisite for this research was the hypothesis about the possibility of improving machine learning methods for software based image enhancement systems. The formulated task can be solved on the basis of software control of the resolution of the image, obtained from CCTV cameras. This can be done by training the neural-like structure of the geometric transformation model with many outputs and by using the matrix operator of the synaptic connection weights coefficients, the use of which will provide effective oversampling of digital scenario images in the on-line mode, for example, video surveillance systems for Smart City.

## 2. LITERATURE REVIEW

Today, the pace of development of software products for video processing systems is far ahead of the development of physical technologies, hardware complexes and systems.

Improving the quality of an image means increasing its information content that is, increasing the scale of the image without large losses of visual information. In connection with the wide development of video surveillance systems, there is a need for appropriate algorithms and programs that will scale the image without losing its quality. The use of image interpolation can be in demand in completely different areas: in security systems to enlarge the image and to obtain clearer features of cars, people and other details, etc.

The simplest method for increasing image resolution is interpolation. During interpolation, the image has a form of a function, where the pixels of the image are the points at which the values of the function are known. The interpolation process is finding new values from a given discrete data set. Accurate recovery of information by interpolation is impossible.

Let us note that over the past decades, with the development of video surveillance systems, there has appeared a fairly large number of theoretical and applied research in the field of image resolution enhancement based on various methods and models.

Video surveillance systems are used today in many applied problems of security control of any digitalization objects [10-12] and, in particular, Smart City. Video surveillance systems, namely technical and software video surveillance tools, allow to determine the nature and location of the violation and take optimal measures of a different nature. In addition, with their help, you can track the adjacent territories. The mentioned systems are significantly improved by the implementation of video analytics modules [13, 14].

The most commonly used method is comparing the current image with the reference one or with the one that was obtained shortly before, and further assessment of the comparison result [15-17]. The disadvantage of this method is that certain optical effects caused, for example, by the headlights of cars or a human shadow, can be mistaken for a foreign object in the path.

The physical limitations of image capturing devices do not always allow to obtain an image, the resolution (RS) of which is necessary for a specific technical vision or video surveillance system. In addition, image recording devices are characterized by the influence of noise of various nature, which leads to the need to use sharpening, filtering, and other procedures.

The importance of the task of image oversampling (OS) is confirmed by a large number of modern scientific works all over the world [15-20]. However, the constantly growing volume of processed information requires new, more efficient methods for solving the tasks of providing super-resolution (SR) of images for specific areas of application. The problem is especially acute in such application areas as monitoring, video surveillance, video conversion, visualization, video communication, etc. That is, in those that are characterized by:

- impossibility or high complexity of obtaining an image of the required resolution;

- non-compliance with the quality criteria of the result obtained;

- high computational costs of the OS process.

The development of computing tools opens up additional opportunities for the use of rather complex or resource-intensive methods for

Journal of Theoretical and Applied Information Technology
31st March 2021. Vol.99. No 6

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

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)).

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.

Most of the methods for improving the quality of images obtained from CCTV cameras and used in video monitoring systems are empirical or heuristic methods. These methods depend on image specific. Most of the methods discussed in the works require interaction with users, as well as setting special parameters. This makes it difficult to use these methods in automatic modes of video monitoring and law violator recognition systems, in particular for Smart City. Finally, existing methods for increasing image quality tend to transform the entire image. At the same time, we note that in many cases it is enough to convert and increase the resolution only for a certain area of the image. The genetic algorithm described in [18] and the corresponding image processing method make it possible to improve the image quality automatically. However, as the authors point out, this does not always give good results.

Therefore, the analysis of previous studies in this area shows that the task of developing methods for increasing or decreasing the resolution of images obtained from CCTV cameras based on the matrix operator of symmetric convergence measures and the crossing over operator remains relevant.

## 3. METODS AND MODELS

The main tasks, which are considered further within the framework of the study, are the development of methods for increasing the RS, for the case of obtaining images from digital CCTV cameras installed at infrastructure facilities, for example, Smart City. The tasks of increasing the RS of images are considered in more detail when it is necessary to avoid some interpolation artifacts (image scaling).

There should be noted that a fairly large segment of CCTV cameras and fixing violations at infrastructure facilities of Smart City is made up of cameras with black and white images (grayscale images) on monitors. These cameras have a lower cost and are still quite common in conditions of low requirements for the quality of images obtained from them under typical operating conditions.

Problem statement.

Let a digital grayscale image be set:

$$P = \left[c_{i,j}\right]_{i=1..h}^{j=1..l}, \tag{1}$$

Where $c_{i,j} \in N^{+}$ – the value of the pixel intensity function with coordinates $(i,j)$.

Let's shift the value of a discrete set of points using the following dependence [21]:

$$c_{i,j} = c_{i,j} + \left( \max_{\substack{i\in[1;h] \\ j\in[1;l]}} c_{i,j} + \min_{\substack{i\in[1;h] \\ j\in[1;l]}} c_{i,j} \right), \tag{2}$$

and normalize the signal ($P$), apply the inverse minimax multiplier scheme [21]:

$$c_{i,j} = K \cdot c_{i,j}, \tag{3}$$

where $K = \dfrac{1}{\max\limits_{i\in[1;h];\, j\in[1;l]} \cdot c_{i,j}}$.

As a result, we obtain: $\forall i \in [1;h],\ j \in [1;l]: c_{i,j} > 0$.

Further, we will consider the oversampling procedures (OS) in the vertical direction (in the direction specified by the index *i*). For each row of the matrix $P$, we construct the operator of relative symmetric convergence measures [22] in the form of a square degenerate symmetric matrix:

$$\forall i \in [1;h], \nabla_i = A_i^T + E + A_i, \tag{4}$$

where

$$A_i = \begin{pmatrix} 0 & \frac{1}{2}\left(\frac{c_{i,2}}{c_{i,1}} + \frac{c_{i,1}}{c_{i,2}}\right) & \dots & \frac{1}{2}\left(\frac{c_{i,l}}{c_{i,1}} + \frac{c_{i,1}}{c_{i,l}}\right) \\ 0 & 0 & \dots & \frac{1}{2}\left(\frac{c_{i,l}}{c_{i,2}} + \frac{c_{i,2}}{c_{i,l}}\right) \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 0 \end{pmatrix}. \tag{5}$$

In formula (4), the E unit diagonal matrix of dimension is denoteв by $\dim E = l \times l$

In the case of oversampling in the horizontal direction, operator (4) and matrix (5) take the following form:

$$\forall j \in [1;l], \nabla_j = A_j^T + E + A_j, \tag{6}$$

where

$$A_{j'}=\begin{pmatrix} 0 & \frac{1}{2}\left(\frac{c_{2j}}{c_{1j}}+\frac{c_{1j}}{c_{2j}}\right) & \dots & \frac{1}{2}\left(\frac{c_{hj}}{c_{1j}}+\frac{c_{1j}}{c_{hj}}\right) \\ 0 & 0 & \dots & \frac{1}{2}\left(\frac{c_{hj}}{c_{2j}}+\frac{c_{2j}}{c_{hj}}\right) \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 0 \end{pmatrix}. \qquad (7)$$

In this case $\dim E = h\times h$. In practical software or hardware-software implementations of the method for changing the RS of an image for creating operators of relative symmetric convergence measures in the direction $j$, the input matrix of the values of the intensity function $E$ is transposed and further formulas (6) and (7) are used.

As a result of algebraic transformations, operator (4) can be written as follows:

$$\forall i\in[1;h], \nabla_i=\frac{1}{2}\begin{pmatrix} 2 & \delta_{1,2} & \dots & \delta_{1,l} \\ \delta_{1,2} & 2 & \dots & \delta_{2,l} \\ \dots & \dots & \dots & \dots \\ \delta_{1,l} & \delta_{2,l} & \dots & 2 \end{pmatrix}, \qquad (8)$$

where $\delta_{m,n}=\left(\frac{c_{i,m}^2+c_{i,n}^2}{c_{i,m}\cdot c_{i,n}}\right), \quad m,n\in[1;l]$.

The dimension of operator (8) is: $\dim\nabla_i = l\times l$

Operator (8) is a square degenerate matrix.

The procedure for increasing the RS of the image obtained from CCTV cameras consists of two successive parts. This, respectively, is the OS of the image in the vertical and horizontal directions. The ordering of the actions of each part of the OS procedure can be arbitrary.

*Increasing the RS of an image.*

Algorithmic representation of the method (hereinafter referred to as - M1) consists of the following steps:

1) construction of a matrix operator of symmetric convergence measures;

2) calculation of characteristic vectors $y_i$ of square matrices, which were constructed according to relations (8) and according to the iterative procedure described in [22, 23];

3) construction of an extended image by adding a vector $c_i + y_i$ to the original matrix $P$ at the position of a row or column. Here $c_i$ − the value of the intensity function of the input image (1) (i.e. the original values, not shifted and normalized by (2) and (3)). And the vector $y_i=(y_{i,1},\dots,y_{i,l})$ – the solution for the iterative procedure based on the pseudo-inverse Moore-Penrose matrix (PIMPM) [22].

These first two parts are sequentially applied to all rows of the matrix $P$ in order to increase the size of a given image in height. In fact, the matrix $P^{(2)}$ of the image increased in two times in the direction $i$ of the image has the form:

$$I^{(2)}=\begin{pmatrix} c_{1,1} & c_{1,2} & \dots & c_{1,l} \\ c_{1,1}+y_{1,1} & c_{1,2}+y_{1,2} & \dots & c_{1,l}+y_{1,l} \\ \dots & \dots & \dots & \dots \\ c_{h,1} & c_{h,2} & \dots & c_{h,l} \\ c_{h,1}+y_{h,1} & c_{h,2}+y_{h,2} & \dots & c_{h,l}+y_{h,l} \end{pmatrix}. \qquad (9)$$

The dimension of the matrix $P^{(2)}$ will be: $\dim P^{(2)} = 2h\times l$.

For the completeness of the procedure for increasing an image, for example, by half, M1 should be applied to all columns of the matrix P. That is, in a similar way, the image must also be oversampled in width. Then the matrix will take the following form:

$$P^{(2)}=\begin{pmatrix} c_{1,1} & c_{1,1}+y'_{1,1} & c_{1,2} & \dots & c_{1,l}+y'_{l,1} \\ c_{1,1}+y_{1,1} & c_{1,1}+y_{1,1}+y'_{1,2} & c_{1,2}+y_{1,2} & \dots & c_{1,l}+y_{2,l}+y'_{l,2} \\ c_{2,1} & c_{2,1}+y'_{1,3} & c_{2,2} & \dots & c_{2,l}+y'_{l,3} \\ \dots & \dots & \dots & \dots & \dots \\ c_{h,1} & c_{h,1}+y'_{1,2h-1} & c_{h,2} & \dots & c_{h,1}+y'_{l,2h-1} \\ c_{h,1}+y_{h,1} & c_{h,1}+y_{h,1}+y'_{1,2h} & c_{h,2}+y_{h,2} & \dots & c_{h,l}+y_{h,l}+y'_{l,2h} \end{pmatrix}. \qquad (10)$$

Now the dimension of the matrix $P^{(2)}$ will be: $\dim P^2 = 2h\times 2l$. It should be noted here that the vectors $y'_j=\{y'_j \mid i=\overline{1,2h}\}, j=\overline{1,2l}$ are a solution to the task for the iterative PIMPM procedure described in [23] for the case of image oversampling in the horizontal direction (6), (7) with the input matrix (9).

*Decreasing the RS of an image.*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The algorithmic representation of the method (hereinafter referred to as - M2) consists of the following parts:

1) construction of a matrix operator of symmetric convergence measures;

2) calculating the characteristic vectors $y_i$ of square matrices, constructed in relation to expression (8), and according to the iterative PIMPM procedure described in [23];

3) construction of an image with a decreased RS of the image by replacing two consecutive rows $c_i$ and $c_{i+1}$ in the matrix $P$ with a vector $c_i + 0{,}5\cdot(y_i + y_{i+1})$. Similar to the method M1, here $c_i$ also are the original values (1), not shifted and normalized according to expressions (2) and (3).

The specified first two steps of the M2 method are sequentially applied to all rows of the matrix $P$ in order to reduce the size of the given image in height. Then with the input matrix (1) instead of matrix (9), we obtain a matrix $P^{(0,5)}$ of the image decreased by half in the direction $i$:

$$P^{(0,5)} = \begin{pmatrix} c_{1,1} + \left(\dfrac{y_{1,1}+y_{2,1}}{2}\right) & c_{1,2} + \left(\dfrac{y_{1,2}+y_{2,2}}{2}\right) & \dots & c_{1,l} + \left(\dfrac{y_{1,l}+y_{2,l}}{2}\right) \\ c_{3,1} + \left(\dfrac{y_{3,1}+y_{4,1}}{2}\right) & c_{2,2} + \left(\dfrac{y_{3,2}+y_{4,2}}{2}\right) & \dots & c_{3,l} + \left(\dfrac{y_{3,l}+y_{4,l}}{2}\right) \\ \dots & \dots & \dots & \dots \\ c_{h-1,1} + \left(\dfrac{y_{h-1,1}+y_{h,1}}{2}\right) & c_{h-1,2} + \left(\dfrac{y_{h-1,2}+y_{h,2}}{2}\right) & \dots & c_{h-1,l} + \left(\dfrac{y_{h-1,l}+y_{h,l}}{2}\right) \end{pmatrix}. \quad (11)$$

Now the dimension of the matrix $P^{(0,5)}$ will be: $\dim P^{(0,5)} = (h\%2)\times l$.

For completeness of the procedure for decreasing an image, for example, by half, the procedure described in M2 should be applied to all columns of the matrix $P$ for the image OS in width.

In accordance with method M1 above, there was developed a software solution. Due to this solution, there was carried out a set of experiments that showed the effectiveness of the developed method.

In most cases, the task of increasing the RS of an image is solved using two input images. Therefore, in the next method, the input data will be images with the same dimension $P_1 = [c_{1\ i,j}]_{i=1..h}^{j=1..l}$ and $P_2 = [c_{2\ i,j}]_{i=1..h}^{j=1..l}$.

At the first stage of the method of increasing the RS for each row (or column), due to the crossing-over operation of the genetic algorithm (GA), there is formed the third vector. As a result, we obtain a new matrix:

$$\tilde{P} = [\tilde{c}_i]_{i=1..h} = [\tilde{c}_{i,j}]_{i=1..h}^{j=1..l}, \quad (12)$$

where $\tilde{c}_{i,j}$ – elements $\tilde{c}_i(\dim\tilde{c}_i = l)$, which are determined by the crossing over operation:

$$\tilde{c}_{i,j} = k\cdot c_{1i} + (1-k)\cdot c_{2i}, \quad (13)$$

where $k$ – crossing over operation coefficient;

$c_{1i}, c_{2i}$ – vectors of the dimension $l$, the elements of which are matrix rows $P_1$ and $P_2$, respectively.

If the image is increased in the horizontal direction, the matrix $\tilde{P}$ will consist of vectors $\tilde{c}_j$, i.e.

$$\tilde{P} = [\tilde{c}_j]_{j=1..l}; \quad (14)$$

$$\tilde{c}_j = k\cdot c_{1j} + (1-k)\cdot c_{2j}, \quad (15)$$

where $c_{1j}, c_{2j}$ – vectors of the dimension $h$, the elements of which are matrix columns $P_1$ and $P_2$, respectively.

The vectors $\tilde{c}_i$ and $\tilde{c}_j$ are pre-normalized in accordance with expressions (2) and (3). These vectors are used to construct a matrix operator by expression (4). The matrix divergence operator $\nabla_i$ itself is constructed as follows:

$$\forall i \in [1;h], \nabla_i = A_i - \left[\underbrace{(\tilde{c}_i \dots \tilde{c}_i)}_{i}\right]^T, \quad (16)$$

$$A_i = \begin{pmatrix} \dot{c}_{i,1} & \dots & \dot{c}_{i,1} \\ \dots & \dots & \dots \\ \dot{c}_{i,l} & \dots & \dot{c}_{i,l} \end{pmatrix}; \quad \dot{c}_{i,1} = \frac{1}{l-1}\cdot\left(\sum_{x=1}^{l}(\tilde{c}_{i,x} - \tilde{c}_{i,j})\right), \quad (17)$$

or in the following form:

$$\forall i \in [1;h], \nabla_i = [\delta_{m,n}]_{m,n=\overline{1,l}}, \quad (18)$$

where $\delta_{m,n} = \tilde{c}_{i,x} - \tilde{c}_{i,j}$, $m,n \in [1,l]$. Let us note, that $\dim A_i = l\times l$.

In the case of a change in the RS of the image in the vertical direction, the divergence operator determined by (16) - (18) takes the following form:

$$\forall j \in [1;l], \nabla_j = \left[\underbrace{(\tilde{c}_j .. \tilde{c}_j)}_{h}\right]^T - A_j, \quad (19)$$

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195



$$A_j = \begin{pmatrix} \ddot{c}_{j,1} & \dots & \ddot{c}_{j,1} \\ \dots & \dots & \dots \\ \ddot{c}_{j,h} & \dots & \ddot{c}_{j,h} \end{pmatrix};$$

$$\ddot{c}_{j,i} = \frac{1}{h-1} \cdot \left( \sum_{x=1}^{h} \left( \tilde{c}_{x,j} - \tilde{c}_{i,j} \right) \right); \tag{20}$$

$$\dim A_j = h \times h;$$

$$\forall j \in [1;l],$$

$$\nabla_j = \left[ \delta_{m,n} \middle| \delta_{m,n} = \ddot{c}_{j,m} - \tilde{c}_{n,j} \right]_{m,n=\overline{1,h}}. \tag{21}$$

The solution of the problem for the pseudo-inverse Moore-Penrose matrix [23] with the operators of the tasks (16) or (21) is used to obtain the RS of the image in case of using the crossing over operation. Since the input information in this case is two images $P_1$ and $P_2$, there are at least two solutions to the oversampling task. Their construction is determined by expressions (10) and (11). In this case, $P_1$ and $P_2$ will be used at the input, respectively.

In addition to the increased images $P_1^{(m)}$ and $P_2^{(m)}$ obtained from $P_1$ and $P_2$, in this case, an additional image $P^{(m)}$ can also be synthesized.

The synthesis formula, for the case of a twofold increase, will have the form:

$$P^{(2)} = \begin{pmatrix} \frac{c_{1\,1,1} + c_{2\,1,1}}{2} & \frac{c_{1\,1,1} + c_{2\,1,1}}{2} + y'_{1,1} & \dots & \frac{c_{1\,1,l} + c_{2\,1,l}}{2} + y'_{l,1} \\ \frac{c_{1\,1,1} + c_{2\,1,1}}{2} + y_{1,1} & \frac{c_{1\,1,1} + c_{2\,1,1}}{2} + y_{1,1} + y'_{1,2} & \dots & \frac{c_{1\,1,l} + c_{2\,1,l}}{2} + y_{2,l} + y'_{l,2} \\ \dots & \dots & \dots & \dots \\ \frac{c_{1\,h,1} + c_{2\,h,1}}{2} & \frac{c_{1\,h,1} + c_{2\,h,1}}{2} + y'_{1,2h-1} & \dots & \frac{c_{1\,h,l} + c_{2\,h,l}}{2} + y'_{l,2h-1} \\ \frac{c_{1\,h,1} + c_{2\,h,1}}{2} + y_{h,1} & \frac{c_{1\,h,1} + c_{2\,h,1}}{2} + y_{h,1} + y'_{1,2h} & \dots & \frac{c_{1\,h,l} + c_{2\,h,l}}{2} + y_{h,l} + y'_{l,2h} \end{pmatrix}. \tag{22}$$

The procedure for increasing the RS of the image, similar to the procedure described using expressions (10) and (11), consists of two consecutive parts. That is, the image is oversampled both in the vertical and horizontal directions.

*Increasing the RS of an image.*

The algorithmic representation of the method (hereinafter referred to as - M11) consists of the following parts:

1) construction of the input vector (15), which, due to the use of the crossing-over operation, is a mutation of the corresponding vectors of the input images;

2) construction of the matrix operator of divergences (16) or (18);

3) calculation of characteristic vectors $y_i$ of square matrices, constructed according to relations (8), and in accordance with the iterative procedure for obtaining the pseudo-inverse Moore-Penrose matrix [23];

4) construction by expression (9) of extended images by adding characteristic vectors to the original matrix $P_1$ or $P_2$, or synthesis of an increased image using (22).

These first three steps (parts) are sequentially applied to all rows of the matrix $P$ in order to increase the size of the given image in height. Only then the matrices of the increased images are constructed using expressions (9) or (22).

Subsequently, the procedure of increasing is performed on the increased images until the variable $m$ reaches a value of 16.

*Decreasing the RS of an image.*

The algorithmic representation of the method (hereinafter referred to as - M21) consists of the following parts:

1) construction of the input vector (15), which, due to the use of the crossing-over operation, is a mutation of the corresponding vectors of the input images;

2) construction of the matrix operator of divergences (16) or (18);

3) calculating the characteristic vectors $y_i$ of square matrices constructed according to relations (8), and in accordance with the iterative procedure for obtaining the pseudo-inverse Moore-Penrose matrix [23];

4) synthesis of an image with a decreased RS.

These first three steps (parts) are sequentially applied to all rows of matrices $P_1$ and $P_2$ in order to reduce the size of the given image in height. Then, with the input matrices $P_1$ and $P_2$ we synthesize the matrix of the decreased in a half image.

Journal of Theoretical and Applied Information Technology
31st March 2021. Vol.99. No 6

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Formula (23) illustrates the synthesis of a two-fold decreased original image in the direction of i.

$$P^{\left(\frac{1}{2}\right)} = \frac{1}{4}\begin{pmatrix} \sum_{j=1}^{2}\left(c_{j\,1,1}+y_{j\,1,1}\right)..\sum_{j=1}^{2}\left(c_{j\,1,l}+y_{j\,1,l}\right) \\ \sum_{j=1}^{2}\left(c_{j\,3,1}+y_{j\,3,1}\right)..\sum_{j=1}^{2}\left(c_{j\,3,l}+y_{j\,3,l}\right) \\ \ldots \quad \ldots \quad \ldots \\ \sum_{j=1}^{2}\left(c_{j\,h,1}+y_{j\,h,1}\right)..\sum_{j=1}^{2}\left(c_{j\,h,l}+y_{j\,h,l}\right) \end{pmatrix}. \quad (23)$$

The dimension of the matrix $P^{\left(\frac{1}{2}\right)}$ will be: $\dim P^{\left(\frac{1}{2}\right)} = (h\%2)\times l.$

Subsequently, the procedure of decreasing is performed on the decreased images until the variable reaches the required value of the reduction by M21 from the input image based on the matrix operators (16) and (18).

Methods M11 and M21 are determined by the fact that the crossover operation is performed in them once and consists in sequentially increasing (or decreasing) the RS of the image to the required values of the oversampling coefficient. This makes it possible to avoid performing the crossover operation at each stage, and therefore reduces the computational costs.

## 4. EXPERIMENTAL RESEARCH

The input image that was used in one of the experiments is shown on Fig. 1 (type - grayscale, dimension – 152x101).

*Figure 1 – Input image*

The number of iterations of the procedure [23] at each step in the process of increasing 16 times ranged from 10 to 12 iterations. This indicates the efficiency of using the pseudo-inverse Moore-Penrose matrix in the developed oversampling method.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

a) *Reference image*

*b) Increased image*

*The Fig. 2 Shows The Results Of A 16-Fold Increase Of The Input Image (A) And The Reference Image (B).*

The Fig. 2 shows the results of a 16-fold increase of the input image (a) and the reference image (b).

Let us note that both images (Fig. 2) are scalable for their presentation in the article.

Analyzed the images shown on Fig. 2, it can be stated that the image that has been oversampled visually practically does not differ from the reference one. That is, an expert assessment indicates a visual almost one hundred percent coincidence of these two images. At the same time, it should be noted that it was possible to completely preserve the fine details of the input image, which were determined by the fluctuation values of the intensity function.

The Fig. 3 shows the PSNR values (hereinafter PSNR - peak signal-to-noise ratio) between the reference images and the corresponding increased images $P(m)$ using the developed methods at various coefficients of increase. And the Fig. 4 shows the modulus of the gradient at various coefficients of increase.

From the graphs given, the following should be highlighted:

✓ by the PSNR value, the developed methods M1 and M2 are qualitatively superior to interpolation methods;

✓ the PSNR value in the range of the coefficient of increase [1, 16] does not change its values significantly;

✓ the gradient of PSNR change on the first part of the range [1, 10] is commensurate in value on the third part [14, 16]. That is, the level of smoothness of the curve is very close;

✓ a jump in the PSNR gradient occurs in the second part of the range of values of the coefficient of increase [10; 14].

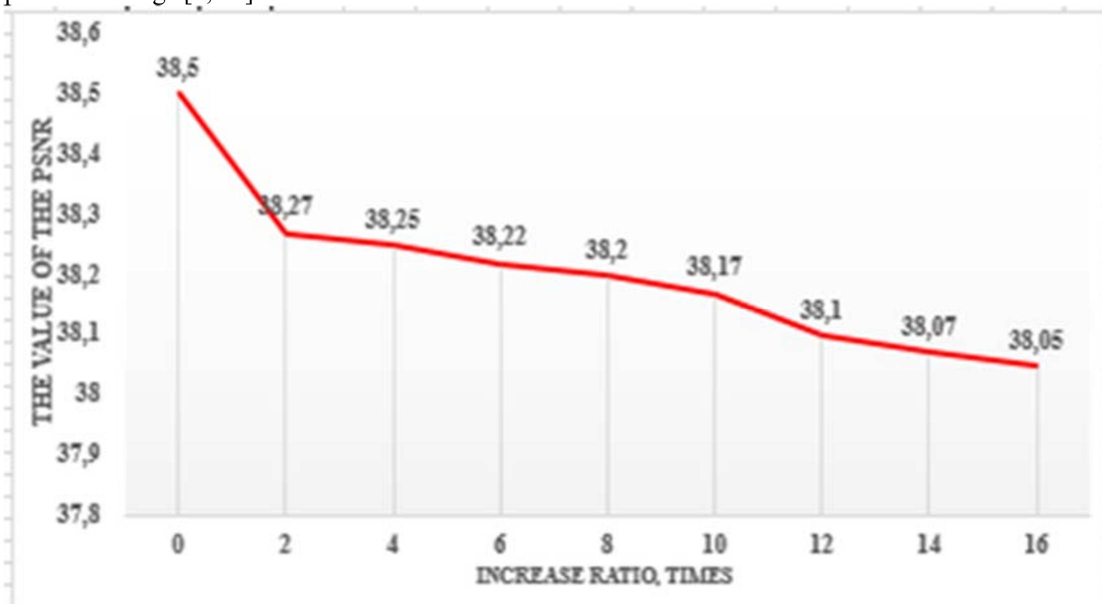


*Figure 3 – Peak signal-to-noise ratio at different increase values*

From the highlighted characteristics, the following conclusions can be made.

For the above method M1, the range of values of the coefficient of increase can be conventionally divided into three parts. In the first part, the increased images will very strongly coincide in PSNR values with the reference images. In the second range, there is a jump in the deviation value from the reference image. However, as the coefficient increases, the noise does not grow very quickly. In the third range, deviations from the reference images will grow very strongly due to the accumulation of noise. Therefore, as the value of the RS increase coefficient increases, the noise increases sharply.

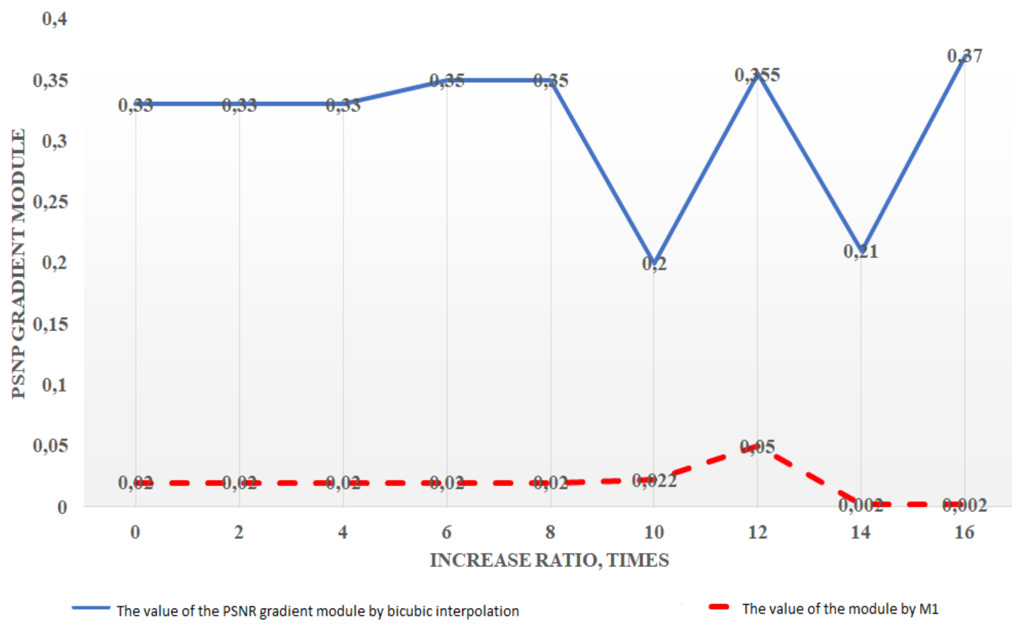


*Figure 4 – Gradient modulus of the peak signal-to-noise ratio at various values of coefficient of increase*



In order to implement the proposed method, here was chosen the Python programming language. Also used: Tensor flow machine learning framework; Jupyter Notebook development environment. This version of the software package provides the user with a convenient interface, functionality and performance.

## 5. DISCUSSION OF THE EXPERIMENTAL STUDIES RESULTS

Comparing the above results, we can state that in the process of sequential increase by 16 times, the use of bilinear interpolation at each step of the increase accumulates much more noise. This noise manifests itself in visual pixelation and contrast changes compared to the input image.

Obviously, in case of using topological approaches, there will appear artifacts on the resulting images from the determination of various disjunctive coverings.

Experiments with other images only confirmed the correctness of the conclusions. In all cases, the coefficient of increase is divided into three parts. However, the boundaries of these parts did not always coincide.

The results obtained in the course of research can be used in software complexes for image processing. At the same time, the main goal of such software products is to increase the RS of both the entire image and its individual parts. These results can be used both in monitoring systems of the situation in Smart City and for monitoring other objects where video surveillance is required. For example, such systems can be used in access control circuits of integrated information security systems [24-26], transport monitoring systems [27-29], etc.

Let us note that the developed improved method for increasing the resolution of images obtained from video surveillance cameras, as well as the projected video surveillance system, can provide the following main opportunities in the future such as [30–32]:

1. recognition of the license plate and verification whether the car is on the wanted list (black list), determination of the compliance of the car and the license plate number with registration documents;
2. recognition of color, type of transport, model and brand;
3. face recognition from different angles from video footage captured from different sources (online stream, files), search for a match in the search database, gender, age group;
4. detection of persons in the front seat of the car, with the possibility of visual perception of a person's face;
5. detection of crowds of people, including in unauthorized places;
6. assessment of the people flow density at the places significant for the city;
7. indexing of events in urban traffic conditions (traffic density, traffic jams, mass traffic), including in parking areas;
8. detection of abandoned items and their owners based on video surveillance;

9. detection of prohibited or atypical traffic, people;
10. detection of the facts of crossing the forbidden zone (passage);
11. response to the passage of people in a given direction (entrances, exits, passages, corridors, etc.);
12. the appearance of a person or a car in the observation area (streets, squares, intersections, parks).

At this stage of research, the system being developed has certain disadvantages. So, in particular, the time delay in the process of transmitting information from the moment of its fixation to the moment it arrives at the dispatcher, while it remains high and can range from 1 to 10 minutes.

This time varies from the performance of computing technology, which allows to implement the proposed improved method for increasing the image resolution. This disadvantage negatively affects the responsiveness of the relevant services to events. Therefore, the prospect of research is the further development of the software component of the method in order to reduce the computational resources required for its implementation. Also, there is a disadvantage associated with the work of algorithms for improving the quality of the image obtained from CCTV cameras in low light conditions. But this disadvantage is inherent in all video surveillance systems in the budget segment.

## 6. CONCLUSIONS

1. Proposed an improved method for increasing the resolution of images obtained from CCTV cameras, for example, for Smart City, for the case of one image based on the Moore-Penrose pseudo-inverse matrix (degenerate matrix operator of relative symmetric convergence measures). Due to this, it was possible to identify characteristics that can be used both for solving the task of increasing the RS and for other tasks of intelligent image analysis in video monitoring systems.

2. The modified method based on the pseudo-inverse degenerate matrix operator of relative symmetric convergence measures provides high efficiency of oversampling by criterion based on PSNR. Moreover, the modified method is characterized by the reduction of artifacts inherent in various types of interpolation when used in the tasks of image oversampling.

3. For the first time, there is proposed a new method for increasing the RS of an image for the case of two images on the basis of the combined use of the crossing-over operation and the pseudo-inverse degenerate matrix operator of divergences. The use of this operator in the case of two images significantly increases the quality of oversampling and minimizes computational costs in practical implementations of algorithms for increasing the RS of an image in video monitoring systems

4. It is shown that the improvement of the method based on the pseudo-inverse matrix operator of divergences makes it possible to increase the efficiency of oversampling with an insignificant increase in computational costs even in cases of noisy images from CCTV cameras. Slight reductions in contrast are not a significant disadvantage as this can be mitigated by any contrast equalization filters.

5. Revealed the regularity of PSNR value change from the value of the image coefficient of increase at the minimum oversampling range. This makes it possible to predict the level of noise in the tasks of hardware and software video surveillance systems with an automated choice of a rational method for changing the RS.



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