Development Latent Images based on Moiré Effect

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Abstract. The paper presents the results of the research concerning development of the latent images identification method, where the filtration process was performed with the use of Moiré effect. The analysis of problems of the current document security state has shown the necessity of development of new current techniques and tools for both the graphic elements visualization and processing and the the creation of effective specialized means of protection on their basis. The identification has been made to prevent violation of integrity and prevent document falsification. The methods and means of forming the latent images for controlling and detecting any distortions in documents have been developed. The construction of fine graphics based on the local distortions of the protective grid lines, changes in the thickness of the lines, contour filling and line separation has been carried out. In order to increase the level of the printed documents security, we have proposed the use of grids created in a vector format. The models of image-based traps on the basis of Moiré effect have been developed. The models become visible when copying by sticking and displacing lines in images which ensures the creation of a high-quality secure document with consideration of conditions at the stage of forming a document for printing. The information technology which includes as the components the methods for the formation of fine graphics on the Moiré effect has been developed. Implementation of this technology allows us to increase the exact of the document originality identification. The technology provides an increase in the identification of document originality. The identification process is performed based on the method of pixel comparisons of an original document and its copies. The obtained methods give the opportunity to predict and identify falsification. The information characteristics of the printed document include optical density, raster point %, uniformity of ink application, compression, trapping, which were measured by special equipment on the originals and copies, and the criterion signs of threshold characteristics were deduced from them. The errors for originals and forged documents have been established based on the measured values. The developed methods provided practical recommendations re-

garding the provision of the appropriate level of printed documents identification and, have improved the reliability of the document which based on the analytical dependence of the original and a copy of the spectrophotometer removed by the indicators

Keywords: image processing, information technology, thin graphics, latent elements, Moiré, document protection, falsification.

1 Analysis printed document which based on latent image

Nowadays, information technologies are used actively in various fields of human life, however their development in the field of document protection is important yet. An important component of this direction is the protective hidden graphic elements that are essential in identifying the originality of documents. Therefore, further development and improvement of the protective properties of these elements requires constant development and improvement. The primary is, of course, visual control, but one cannot cope with the analysis of the complex structure of the latent elements and provide the necessary productivity of processing the differences on the original and the falsified document, so identification is advisable to make using an automated information system [1]. Existing computerized image analysis systems are largely universal in nature and can perform such functions as image database formation, contrast enhancement, identification of input mismatches, but are not suitable for highly specialized tasks. This leads to the fact that the images hidden in the printed documents, which are characterized by complex structure, rely on the expert. The lack of automation in visual data processing results in low performance, ambiguity, and errors in analysis. Therefore, the urgent task is increasing the security of printed documents by developing information technology for the formation of latent elements and establishing their accuracy [2]. The hidden image can also appear after scanning or copying the latent image due to the anisotropy of scanning and printing devices.

The latent image development efficiency depends on the vector format lines that form the image layers with preset gradient properties [3]. Therefore, the first group of tasks is focused to the development of a method of protecting printed documents based on the selection of objects in images with complex geometric structure. The formation and detection of images containing hidden information is produced by digital devices. Unlike known analogues, the method of forming latent images on the basis of lines of vector format allows us to form images with layers and to set gradient properties for image protection. Thus, this method allows automatizing the process of forming geometric elements, which provides improved accuracy of metric measurements.

Latent images have the property of changing the visibility of the elements when changing the conditions of observation, which provides identification of the document due to the protective properties of the image [4]. This requires the development of technology in order to create and detect the hidden part, which creates requirements for printing accuracy and complexity of reproduction. Development of information

technologies that identify document forgery is included in the list of priorities in the field of information and communication technologies.

1.1 Algorithms of latent images formation

Existing methods of forming latent images are divided into two groups: spatial and frequency ones. The essence of spatial methods is consisted in transforming the brightness of the original image or one of its color components. Frequency methods involve changing the original image in such a way that when the frequency decomposition of the resulting latent image, the hidden image appears in the localized frequency domain, as a rule, low-frequency [5].

The latent image creation method assumes forming two superimposed hidden images. Determine the relief elements for each hidden image transmitted by the corresponding linear structures forming the main and auxiliary layers. The elements are built only in places where the linear relief structures of the first and second layers are superimposed. The layer and the hidden image will be reproduced when copied as a permanent gray area. In [6] the authors developed the information technology for the development of graphical security documents. This technology includes the following: the method of formal description of graphical security, which has allowed determining the basic parameters characterized the security of documents; the mathematical model for both evaluation and investigation of graphical security; quickly change their security level and provide simple and efficient identification of documents. The moiré method is to create thin parallel lines, with a width of 0.25mm and repetition rates that are multiple of the integer frequency of the reproducing device and differ from the copy / scan frequency by a magnitude less than 0.25mm, which is not visually recognizable without the use of special optical devices. The hidden element document contains at least one latent image, which consists of a large number of visible and individually printed elements, which in turn constitute a security object formed from curved lines and fragments.

When copying a document, the moiré is formed, and it becomes easy to distinguish between the original and the counterfeit by changing the latent image or partial distortion or the loss of certain elements on the copy.

The basic idea of the method is that for the hidden elements, the displacement of part of the moire lines is half the magnitude of the line step.

Method of forming a latent image with implementation image

Latent images built using this method are unstable to the destructive processes associated with transmission. However, the advantage of this method is the ability to imple-ment a full-color hidden image [7]. Implementation of this technique assumes the following steps:

1. The hidden image $S\ (x, y)$ is decomposed using several raster structures to obtain the matrix $S_r\ (x, y)$ in total with the matrix $S\ (x, y)$:

$$S_r(x,y)=k_1 S(x,y)+k_2 R_i (x,y),$$

where $R_i (x, y)$ is a set of raster structures; k_1, k_2 are positive constants.

2. The $S_r (x, y)$ matrix is combined with an inverted copy of the hidden image $S_{inv}(x,y)$, resulting in the matrix $S_{pre} (x, y)$:

$$S_{pre}(x,y)=k_1 S_{inv}(x,y)+k_2 S_r (x,y),$$

3. The matrix $S_{pre} (x, y)$ is transformed into the matrix $S_{adj} (x, y)$ through the use of the coefficient α:

$$S_{adj}(x,y) = \alpha S_{pre}(x,y)$$

4. A latent image $L (x, y)$ is formed by combining the main image $I (x, y)$ and the image with a modified contrast $S_{adj} (x, y)$:

$$L(x,y)=k_1 I(x,y)+k_2 S_{adj} (x,y),$$

The mathematical model of forming a latent image by this method is represented by the following system of equations:

$$\begin{cases} S_r(x,y) = k_1 S(x,y) + k_2 R_i(x,y), \\ S_{pre}(x,y) = k_1 S_{inv}(x,y) + k_2 S_r(x,y), \\ S_{adj}(x,y) = \alpha S_{pre}(x,y), \\ L(x,y) = k_1 I(x,y) + k_2 S_{adj}(x,y), \end{cases}$$

2 Analysis of reasons of the printed defects appearing based on Moiré effect

Copying of printed grids with a low reproduction rate causes a Moiré defect. This phenomenon allows us to create moving images. Moiré is the result of the interference of two or more periodic structures which have different spatial frequencies [8-12]. Hidden elements can be displayed with the Moiré effect when copied, thus making the falsification noticeable. Moiré effect occurs when multiple layers are used, namely, when the base layer depicts the surface of a periodic structure in the form of opaque and transparent parallel changing stripes [13].

Let's consider the problems of developing the Moiré-based graphical trap models which allow the elements to be original by changing the lattice periods, tilts, and line thicknesses. The moiré effect occurs when the reading of information is disturbed and the original image is distorted, in particular, resulting in uneven shades and colors. The appearance of such Moiré effects is difficult to predict because it depends on the specifications and regulation used to reproduce the equipment [14, 15]. Considering all the peculiarities of the moiré method [16], the classical method of masonry formation was chosen as the basis for dissertation work, since it is suitable for the vast majority of cases of image distortion and is relatively simple. Based on the developed

methods, a system of image formation with hidden Moiré, which allows us to detect deformation in the latent image, is proposed. To reduce the number of falsifications and to increase the level of detection of document forgery, more than two grids should be used, provided that the frequency of the second grid is a multiple of the frequency of the first and the frequency of the next grid is the previous one. This achieves a higher level of protection and protects the document from copying, because moiré will show up.

3 Development of technique of latent image creation

The mathematical model of the latent image is built by combining different structures based on the creation of positive and negative masks. Assume that there is the main image, where x, y, z is the color intensity of the current pixels in the RGB system [17]. Then, there is the hidden image with the inverted mask. Let L be the number of layers. The process of forming a latent image consists of creating a hidden image with an inverted copy of the main image:

$$G_{inv}(x,y,z)=(2^L-1)-G(x,y,z).$$

The main image $G(x,y,z)$ is formed with the removal of odd diagonal lines, forming the first low-frequency aperiodic structure $R_1(x_i, y_i, z_i)$:

$$R_1(x_i, y_i, z_i) = F_{R1}(G(x_1, y_1, z_1))| \quad {\scriptstyle i=1,\ldots,N;\ j=1,\ldots,M;\ k=1,2,3.}$$

where F_{R1} is the raster function of the low-frequency aperiodic structure, k is the color component in the *RGB* system: $k = 1$ *is red;* $k = 2$ *- green;* $k = 3$ *- blue;* i, j are the coordinates of the current pixel; N, M is the limit value of pixels responsible for image width and height.

The inverted copy of the image $G_{inv}(x, y, z)$ is formed by the removal of paired diagonal lines, forming the second low-frequency aperiodic structure $R_2(x_i, y_i, z_i)$:

$$R_2(x_i, y_i, z_i) = F_{R2}(G(x_1, y_1, z_1))| \quad {\scriptstyle i=1,\ldots,N;\ j=1,\ldots,M;\ k=1,2,3}$$

The next step consists of creating a mask by combining aperiodic structures $R_1(x, y, z)$ and $R_2(x, y, z)$:

$$H(x, y, z) = R_1(x, y, z) + R_2(x, y, z).$$

The latent image $\mathrm{L}(\mathrm{x}, \mathrm{y}, \mathrm{z})$ is formed by embedding the main image $G(\mathrm{x}, \mathrm{y}, \mathrm{z})$ and the inverted copy - an additional layer and mask $H(x, y, z)$:

$$L(x,y,z)=G(x,y,z)+G_{inv}(x,y,z)+H(x,y,z).$$

The initial image is decomposed, then the raster point is shifted in a certain direction in a step smaller than the period of the raster structure. The latent image creation method is formed by forming two superimposed hidden images. Determine the relief elements for each hidden image transmitted by the corresponding linear structures to form the main and auxiliary layers. The elements are built only in the places where the linear relief structures of the first and second layers are superimposed. The layer and the hidden image will be reproduced when copying the gray area. The scheme of forming a latent image is shown in Figure 1.

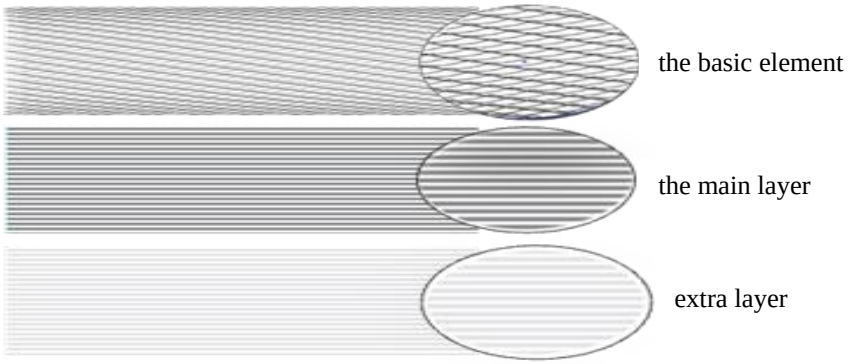

Fig. 1. Scheme of forming a latent image.

The task combines of determining the graphical characteristics of the structural components of images formed by latent elements with the use of technologies for processing, analysis and recognition of thin lines when forming a latent image for printed documents. To solve this problem, the method of creating latent elements has been improved. Implementation of this method at the stage of forming secure documents creates the conditions for the choice of positive and negative lines, which provides visualization of hidden elements during copying and allows to detect distortions in documents. As a result, the methods which are based on image processing technologies and in accordance with regulatory documents have been developed. Based on the method of deformation of the grid lines based on smoothing and the method of deformation of the grid lines on the basis of small perturbations of element forming, the functional possibilities of creating graphic elements for positive execution of lines 40 - 80 microns and for negative 60 - 100 microns are characterized. decomposition of vector lines into raster dots during copying.

4 Development of a latent image based on Moiré effect

Moiré effect is appeared when the readout is disturbed and the original image is distorted, and in particular gets uneven shades of colors and layers. The appearance of a such moiré effects is difficult to predict because it depends on the specifications and the tuning of the equipment that reads the information. Considering all the peculiari-

ties of the moiré method, the classical masonry method was chosen as the basis for the tasks, since it is suitable for the vast majority of cases of image distortion and is relatively simple. Based on the developed methods, a system of image formation with hidden moiré, which allows to detect deformation in the latent image, is proposed.

The method of constructing graphical traps based on Moiré formation is used to create thin parallel lines, with a width of 0.25 mm and frequencies that are multiples of the integer repetition rate. Moiré effect is the result of the interference of the raster grids of the print and the scanning device when attempting to falsify. The presence of moiré elements distorts the appearance of the document and results in significant changes to the shape or complete loss of the image elements on the copy, making it easier to visually distinguish the fake copy from the original. The base layer contains lines that are evenly spaced with the period T_r and are angled α_r at the beginning of the reference system. The auxiliary layer will have a line repetition period T_b and a slope α_b. The overlay of the base and auxiliary layers creates a Moiré lattice, which is shown by the dotted line. Figure 2 shows that the nodes of the Moiré lattice will have a length l and be at an angle α_m. The projections on the axis of the base and auxiliary layers p_b, p_r and p_m are the projections of the Moiré. We calculate the periods T_b, T_r, and T_m by the formulas:

$$T_b = p_b * \cos\alpha_b, \qquad T_r = p_r * \cos\alpha_r, \qquad T_m = p_m * \cos\alpha_m.$$

Hidden elements are formed based on the use of the moiré effect, which is formed by two structures of parallel lines. Even more complex to counterfeit, and therefore more reliable, are the elements formed by combining two parallel line structures with varying angles. The generated hidden elements during tampering become visible and, thus, can be identified fake. The developed method of forming graphical traps on the basis of moiré effect is effective and difficult to fake, in the process of creating a copy of the document moiré effect becomes visible and visually distorts the document. The results can be used to protect printed documents that need effective protection and further identification.

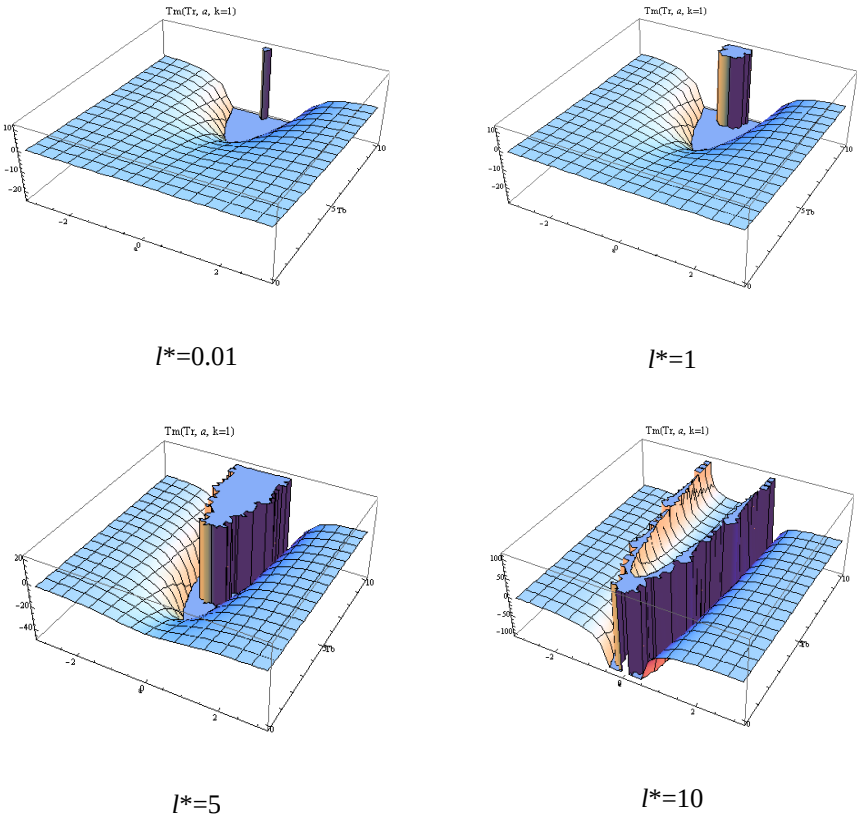

Fig. 2. Dependence of the period of change of the Moiré lattice on the angle the slope of the lattice base layer and the base layer period

The method of Moiré formation consists of both the security elements and the displacement of part of the Moiré lines is halved by half the step size of the line. Another option is to rotate the lines to an angle, as a result, the contour of the image is broken into straight lines. If you change the slope in straight lines, you can observe the Moiré effect in the form of gratings, which will change with the slope angles of 5^0, 15^0, 45^0.

If the base and auxiliary layers are constructed with the same thickness of lines. The period is equidistant from each other:

$$T_m = \frac{T_b}{\sqrt{2 * (\cos\alpha_r \cos\alpha_b + \sin\alpha_r \sin\alpha_b)}}.$$

If we assume that α_r = 0, then $\cos\alpha_r$ = 1.

$$T_m = \frac{T_b}{\sqrt{2 * \cos\alpha_b}}.$$

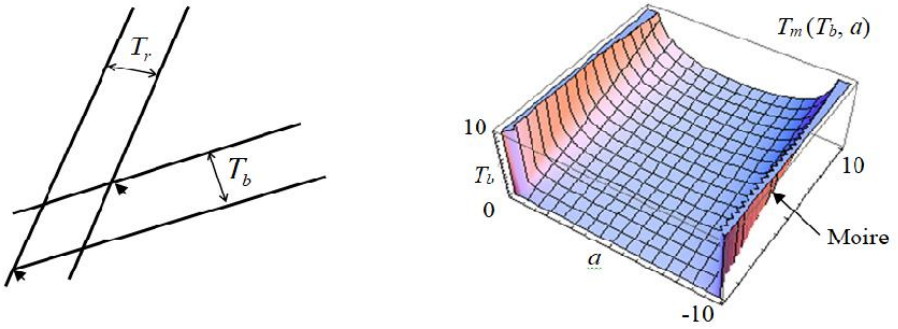

Fig. 3. Scheme of the period of change of the Moiré lattice from the angle of inclination of the lattice of the base layer and the period of the base layer

The auxiliary layer has a period of k-times smaller than the period of the base layer. Therefore, there are the periods of the base and auxiliary layers differ in k-times. The moiration period is calculated by the formula:

$$T_m = \frac{kT_r}{\sqrt{k^2 + 1 - 2k\cos(\alpha_r - \alpha_b)}}.$$

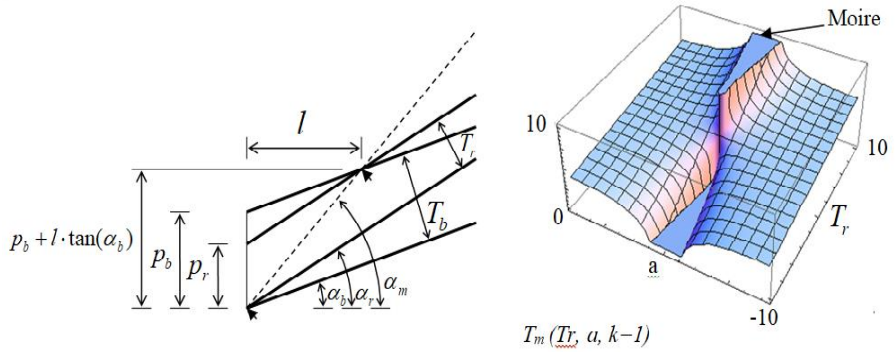

Fig. 4. Scheme of the period of change of the Moiré lattice from the angle of inclination of the lattice of the base layer and the period of the base layer when the period of the base layer was 8 times larger than the auxiliary

The thickness of the base layer lines is k-times greater than the thickness of the auxiliary layer lines. Formation of Moiré lines which depend on the slope angle α of the base and auxiliary layers:

$$T_m = \frac{(T_b + l^*) * T_r * \sqrt{\frac{(T_b + l^*) - T_r}{(T_b + l^*)(\cos\alpha_r - \sin\alpha_r) - T_b}}}{(T_b + l^*) * \cos\alpha_r - T_r}$$

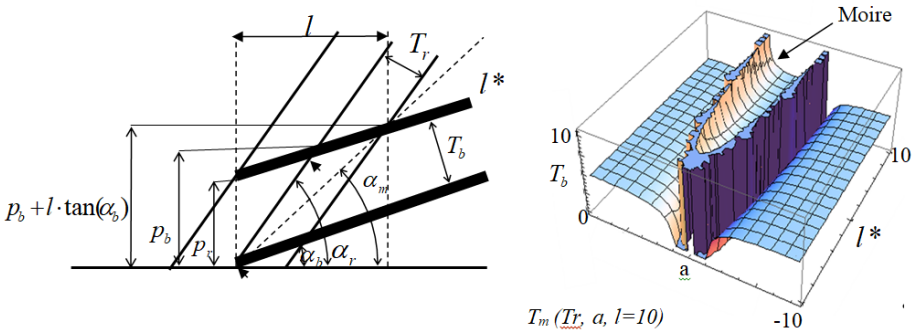

Fig. 5. Scheme of the period of change of the Moiré lattice from the angle of inclination of the lattice of the base layer and the period of the base layer

Figure 5 shows the formation of a moiré with different angles and with different line thicknesses. For the first time, moiré-based graphical trap models have been developed that control the originality of images by changing the lattice periods, tilts, and line thicknesses.

It is proved that the larger the period of the base layer, the more noticeable is the Moiré. Therefore, by increasing the thickness of one of the lines, we increase the visibility of the Moiré. This enhances the security of documents using this method of forming and emitting moiré, forming a latent element in the documents, thereby increasing the level of security.

Conclusions

The necessity of creating models and methods of forming graphical elements for providing the level of security of the document with the help of graphical elements based on traps using Moiré effect is substantiated.

For implementation of processes of the hidden images formation we have developed the corresponding algorithms and methods of their formation. The system of forming the hidden images has been developed on the basis of the offered methods allowing us to represent processes from the moment of formation to the certainty of the protected document.

Considering all the peculiarities of the moiré method, the classical method of masonry formation was chosen as the basis for dissertation work, since it is suitable for the vast majority of cases of image distortion and is relatively simple. Based on the developed methods, we have proposed the system of image formation with hidden moiré, which allows us to detect deformation in the latent image. Printed animated graphic images based on the Moiré phenomenon and optical illusions have been developed too.

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