GRAPHIC CIPHER OF NOSTRADAMUS

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Abstract

Graphic cipher of Nostradamus was first discovered by the author and approximate methods for recovering encrypted images have been proposed. The encryption method of Nostradamus is essentially scytale cipher, which was adapted to transmit images instead of text. This method could have scientific value in the 16th century, without reference to the meaning of the hidden images, which is currently unclear. Given the rather high complexity of such a cipher, it is possible that these images carry the main substantive content of the texts under consideration. Problems such as improving methods for pattern processing and identifying new images, mathematical criteria for distinguishing encrypted images from spillover pareidolia effects, and interpreting the images in a historical context remain relevant. The proposed original approach can serve as the beginning of a conceptual shift in the study of the prophecies of Nostradamus – from interpretations of foggy texts to the image recovery and recognition. The obtained results are essential for the history of steganography and shed a fundamentally new light on the work of Nostradamus.

Keywords Nostradamus, graphic cipher, steganography, image processing, patterns
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1 Introduction

"The Prophecies" of Nostradamus were published in 1555–1568 in the form of 10 blocks (so called "centuries") of 100 quatrains in each (with the exception of the 7th century, which remained incomplete and contains only 42 quatrains), and two prosaic prefaces to them, dedicated to the seer's son Caesar and the king of France Henry II [1]. Although thousands of books and articles are devoted to the prophecies of Nostradamus [2], a scientific study of his life and works began relatively recently. At the moment, it includes a detailed biography of the predictor [3,4] and historical and philological commentaries on the quatrains [5,6]. An important result of these studies was the discovery of the fact that many quatrains describe events preceding 1555, that is, instead of predicting the future, Nostradamus describes the past. Perhaps, Nostradamus believes in the repeatability of history, but in the absence of dating of such quatrains, they do not seem prophetic, and even give the impression of mystification. According to most researchers, the order of quatrains can be considered random, so that a semantic relationship between neighboring quatrains is not traced. Attempts to restore the correct order of quatrains on the basis of astronomical data contained in some of them, failed [7], as it can be seen from subsequent studies, astronomical data in quatrains were misunderstood [5]. Some researchers claim occult symbolism and strange patterns in the numbers used by Nostradamus, but their meaning remains unclear [8].

Herewith, there are strange facts that cannot be reasonably explained in any of the proposed approaches. Firstly, despite the title of the work ("The Prophecies"), many quatrains are clearly not prophetic in nature, either describe banal everyday situations, or, on the contrary, have a too surreal plot. Neither restoring the correct sequence of quatrains, nor discussing them in a historical context, contribute to understanding the purpose of such quatrains (although, of course, an allegory can be assumed in any case). For example, 29 quatrain of 4 century: *"The Sun hidden eclipsed by Mercury / Will be placed only second in the sky: / Of Vulcan Hermes will be made into food, / The Sun will be seen pure, glowing red and golden"*, or 44 quatrain of 2 century: *“The Eagle driven back around the tents / Will be chased from there by other birds: / When the noise of cymbals, trumpets and bells / Will restore the senses of the senseless lady”.* Secondly, astronomically dated quatrains are discovered for which the date indicated by planetary conjunctions is in the past relative to 1555 and will not be repeated in the future, right up to the very end of the prophecies (which, according to studies [5,8], coincides with the end of 6000 years of Jewish calendar). For example, 67 quatrain of 10 century: *“A very mighty trembling in the month of May, / Saturn in Capricorn, Jupiter and Mercury in Taurus: / Venus also, Cancer, Mars, Annonay / Hail will fall larger than an egg”.* Here the planetary configuration (Saturn in Capricorn, Jupiter, Mercury and Venus in Taurus, Mars in Cancer) clearly indicates May 1549, when an earthquake did happen in France, and a large hail fell in the town Annonay [9]. Due to the fact that a unique planetary configuration is indicated in the quatrain, the hypothesis that Nostradamus believes in the repeatability of historical events is not justified in this case.

At the same time, we have no sufficient reason to consider Nostradamus a clever mystifier. Nostradamus was an educated, well-off and respected person, apparently he received his doctorate (1534), for some time he was friends with the famous humanist and philologist J. Scaliger (~ 1536), selflessly fought with plague epidemics in Marseille, Aix-en-Provence and Lyon (1544–1547) [3]. The publication of “The Prophecies” was not the main part of his earnings, moreover, the three final centuries were first published only in 1568, that is, two years after the death of the prophet. It can be assumed that Nostradamus was serious about his hobby and did not make “The Prophecies” with the aim of mystification.

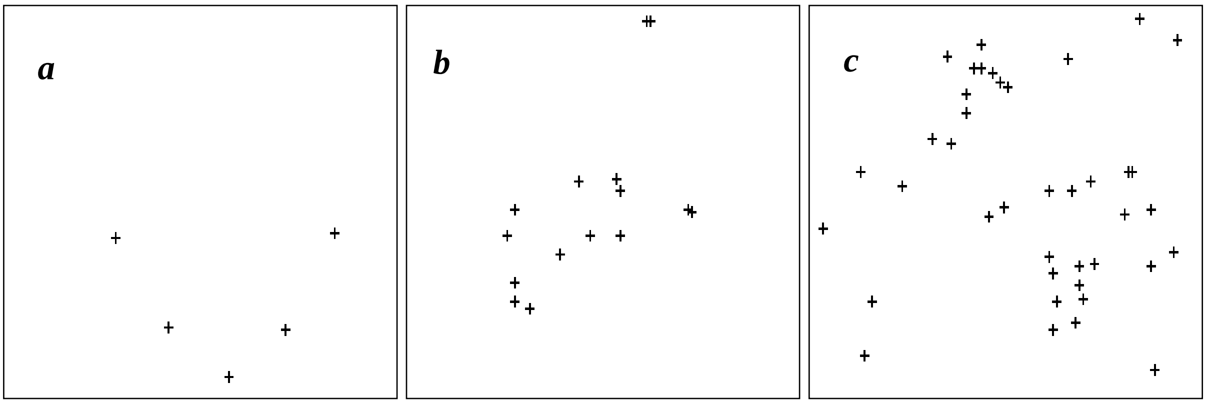

Fig.1 Patterns of points obtained for words with roots “bras” *(a)*, “arab” *(b)* “contre” *(c)* in quatrains of Nostradamus. The points are plotted in accordance with formula (1).

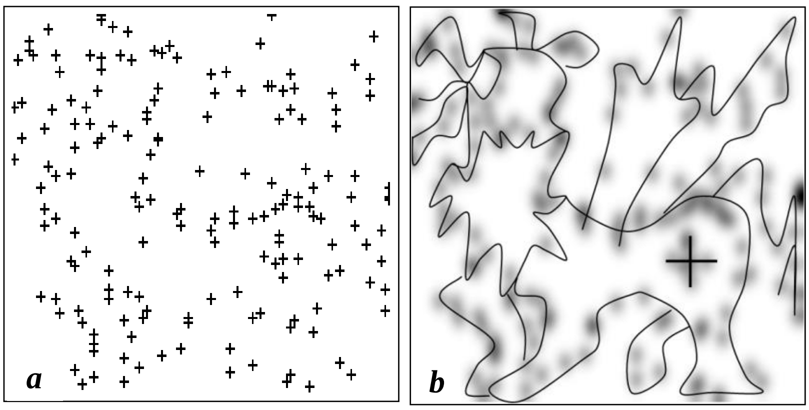

Fig.2. The image formed by 170 first unique words in quatrains from a list sorted alphabetically. The points are plotted in accordance with formula (1). The original image ***(a)*** and manual markup – presumably a winged lion ***(b)***.

Thus, at the moment, the supposed predictive motivation and the meaning of "The Prophecies" eludes researchers. According to Prof. D.Crouzet, *“Nostradamus wrote without knowing what quatrains mean. Even if we assume that the prophetic text was endowed with* *meaning, it loses it and fills the reader with a sense of his own powerlessness and sinfulness [...] Nostradamus makes it clear to his reader that you need to boldly look beyond those words"* [10]. Let us notice that the obscure structure and vague content of "The Prophecies" can be indirect signs of the presence of the cipher that remains unknown.

The author of this article found that patterns composed, for example, of the identical words in "The Prophecies" plotted on a plane in the coordinates "quatrain number – century number", often show signs of a reasonable arrangement: symmetry elements, clusters, equidistant points, which suggests the existence of a graphic cipher (see Fig.1 and Fig.2). From a mathematical point of view, such a cipher is similar to the well-known "scytale cipher" [11,12] (tape is wound on a cylinder and the text is written along the cylinder axis), wherein the length of the circle is equal to 100 (the quantity of quatrains in the block -"century"). A similar procedure also applies to two prosaic prefaces, the text of which can be presented in the form of a tape, and the diameter of the cylinder can be found by fitting. Further analysis of the cipher is carried out in two directions: (1) rules for forming patterns (for example, selection of all words beginning with given letters of the alphabet) and (2) methods for processing them to improve visual perception (smoothing, noise filtering, image deconvolution, and automatic coloring based on machine learning algorithms). Since the original processing method of Nostradamus is unknown, the obtained images are an approximation of the original.

As a result of the study, mostly drawings of human faces, made in a style reminiscent of surrealism, were discovered. Since the graphic cipher covers the entire text of "The Prophecies" and required great efforts from its author, it can be assumed that the creation of this cipher was the main intention of Nostradamus. Therefore, some quatrains may not have clear content or describe past events, but they serve as building material in a graphic cipher. Perhaps the practical value of such a cipher is defined by the ability to identify specific people. However, it is unlikely that the quality of drawings achieved so far allows this to be done. The search for more adequate methods for recovering encrypted images is a creative challenge requiring participation of specialists in the field of pattern analysis and image processing.

Research aim of this paper is to show the existence of a graphic cipher of Nostradamus, to propose rules for forming and processing patterns, as well as to discuss the obtained results in a historical context. The interpretation of the obtained images is not the purpose of this work, and remains the subject of further research.

2 Methods: pattern construction and processing

2.1 Algorithm

The algorithm of the proposed method is as follows.

(1) A supposed rule is formulated by means of which a certain group of words or letters in the text can be selected. It was found empirically that such a group may contain, for example, all words *beginning* with a given letter of the alphabet, all words *containing* a given letter of the alphabet, all words used a given number of times, etc. The specific selected groups are clear from the examples presented in Section 3.

(2) The words of selected group are plotted as points on a plane using formulas qualitatively similar to the well-known "scytale cipher" [11,12]. By default we accept that the patterns are plotted white on black, the opposite situation corresponds to brightness inversion. In some cases (as seen in the figure captions in Section 3), the pattern can be rotated 90, 180, or 270 degrees.

Since the original poetic text is divided into 10 blocks ("centuries") of 100 quatrains each, the quatrain number N_k and century number N_c serve as natural coordinates indicating the position of the selected word in "The Prophecies". However, in this simplest case, we have too low a resolution (10 possible positions) along one of the coordinate axes. The author found that the resolution can be increased by taking into account the quatrain string number N_s (it can take integer values from 1 to 4), as well as the relative position of the word in the string, $0<q<1$. Then the position of the selected word or letter of poetic text on the plane (X,Y) is defined by formulas

$$X=2N_k\,, \qquad Y=20(N_c-1)+5(N_s-1)+\mathrm{Int}(1+5q), \tag{1}$$

where the operation “Int” means discarding the fractional part of a number; the chosen grid size is 200x200. The region of the pattern corresponding to the unfinished part of seventh century will be filled with points using a random number generator.

In the case of prose texts (“Preface to Caesar” and “Preface to King Henry”), we do not have a predetermined scale, and therefore we use the formulas of the scytale cipher in a more general form. We represent the text in the form of a long tape, and perform numbering of the characters. The character with the number i will be denoted by a point on the plane (X,Y) with coordinates

$$X_i= (i \text{ Div } N)+1, \;\; Y_i = i \text{ Mod } N \tag{2}$$

(operations Div and Mod mean the integer division and the remainder after integer division, respectively). Here the number N has a meaning similar to the circumference in the scytale cipher. As a result of variation N, encrypted images can be found.

As an example, Figure 2 shows a pattern obtained from 170 first “unique” words in quatrains (that is, the words found only once in the text, such as “absolution”, “Achilles”, “Aconile”, etc) from a list sorted alphabetically. These words form probably the outlines of a winged lion with a cross on his hip (a similar emblem is widely known as the symbol of Venice, the lion of St. Mark). A formal sign of the presence of an image in this case is the fact that most of the points are located on segments of smooth curves, forming a closed loop, which would be unlikely if the points were randomly generated. The presented image is gradually rebuilt with increasing number of points so there is some bizarre ornament *at each stage* (see Fig.A9 in Appendix).

(3) As a result of displaying of some words or letters from the source text as points on the plane, we have a discrete image, the visual perception of which is difficult, especially if the number of points is large. To facilitate visual perception, it is necessary to convert the pattern to a continuous image. For this purpose, we have used the model of point light sources or the method of reconstruction an image by line segments (see detailed description in Section 2.2). Standard methods of image enhancement implemented in the technical computing system “Wolfram Mathematica” were also used for additional image processing. The application of these methods involves the use of periodic boundary conditions.

Although we have used different processing methods, it should be noted that image structure does not depend on the choice of method. Rather, it is about choosing one of the noise filtering methods to get the clearest image. Figure 3 shows a comparison of the results of using different methods in processing one of the patterns.

(4) At the final step, we used automatic coloring of monochrome images using the services https://palette.fm, https://algorithmia.com, http://color.artlebedev.ru, http://hotpot.ai, based on machine learning algorithms. Although this procedure is very arbitrary, the multi-colored segmentation of the image facilitates visual perception. We emphasize that the coloring process fully conserves the structure of the image, which can be converted back to monochrome using any available method. All steps of our algorithm for each obtained image allow for independent verification, with the exception of automatic coloring.

2.2 Pattern processing

Filtering of noise and smoothing

The main idea is to consider a discrete image as an image containing high-frequency noise. Then filters designed to reduce high-frequency noise can be used to improve visual perception of the image. The simplest of these filters is the “Mean” filter, in which the brightness value of each pixel of the image is replaced by the average brightness value of pixels within a given radius [13]. To reduce random noise, the “Blur” filter is more commonly used, in which the brightness of each pixel is scattered over the entire space with a Gaussian weight [14]. Thus, in both cases, the bright point of the pattern is replaced by a round spot with sharp (the case of “Mean” filter) or blurred boundaries (the case of “Blur” filter). These filters, as well as more advanced filters, are implemented, for example, in the technical computing system “Wolfram Mathematica” [15]. However, their application to our problem gave less satisfactory results compared to the two filters (“Model of point light sources” and “Reconstruction of image by line segments”, see description below) that we created specially. The first of these filters is similar to the “Blur” filter, but is characterized by non-Gaussian light scattering. The idea of the second filter is to use a spot extended in the direction of the nearest cluster of pattern points instead of a round spot. The main step in our image processing is to use one of the two filters mentioned.

Additional processing, which does not lead to large qualitative changes, consists in using standard tools of the technical computing system “Wolfram Mathematica” [15]. Among these methods, our attention was attracted by “FourierDCTFilter”, which reduces noise by the discrete cosine transforms [16]. Since the elimination of defects is always accompanied by blurring of the image as a whole, our attention was also drawn to the image deconvolution method [17], which restores the sharpness of the image, and implemented in “Wolfram Mathematica” as the “ImageDeconvolve” function. At the final stage of processing a monochrome image, we use these two filters together.

Model of point light sources (PLS-model)

Imagine that the pattern points are point sources of light that falls on a screen located parallel to the plane of the pattern. In this case a continuous image appears on the screen, and the degree of light scattering is determined by the distance h from the plane of the pattern to the screen. It is easy to show that the illumination of the elementary area (pixel) on the screen with the coordinates **r** is determined by the formula [18]

$$S(\mathbf{r}) = \sum_i \sigma_i / \left(h^2 + R_i^2(\mathbf{r})\right)^p \qquad (3)$$

where σ_i are the powers of point sources, $R_i(\mathbf{r})$ is the distance between the pixel coordinate **r** and the projection of the source i onto the screen. In the physical model p=3/2, but in this work we use other values. We also found that image quality can be improved if an iterative procedure is used to calculate source powers, $\sigma_i^{(n+1)} = \sum_i \sigma_i^{(n)} / \left(h^2 + R_i^2(\mathbf{r})\right)^p$, where $\sigma_i^{(1)}$=1. Thus, as a result of applying this filter, each point of the original pattern is replaced by a round spot with strongly blurred boundaries. In the area where light spots overlap each other, their brightness is summed up.

Reconstruction of image by line segments (LS-method)

Connecting the points of a pattern by line segments seems to be the most natural operation. However, it is difficult to specify a strict criterion, the fulfillment of which requires drawing a line through two points. The search for such rules involves a nontrivial analysis of some neighborhood of a selected pair of points, which would shift the focus of our research to the pattern recognition [19]. Another possibility is to construct an image grid by connecting each point of the pattern with several of its nearest neighbors, for example, with four neighboring points. However, our study showed that the resulting images in this case are of poor quality due to the irregularity of such a grid. At the same time, the connecting of each point of the pattern with *all* points of its environment within a given sufficiently large radius led to positive results.

In a first step of this method, each point of the pattern is connected by lines of a width d to all its neighbors within a radius R_1; at the intersection points of the lines their brightness is summed. For the commonality, we accept that the brightness of the line connecting the two points depends on the distance r between these points, according to the law ~ $1/r^m$. The choice of $m>0$ means that the brightness of a point with a given coordinate is determined primarily by the points of its immediate environment. In the second step, smoothing of the obtained picture is performed. Each pixel of image with brightness higher than critical value s_1 is connected by lines of width d to all pixels with brightness higher than s_2, located from it no more than R_2.

Since the brightness is summed at the intersection points of the lines, and the line segments connecting the distant points are displayed with lower brightness, the result of the method is quite close to replacing each point of the pattern with a blurred light spot. The main difference from the previous (PLS) method is that the shape of the light spot is not symmetrical. The spot is extended in the direction of those areas in which the average density of the points of the pattern is higher. As a result, the contour lines of the images are better drawn. The disadvantage of the method is that at a low density of points it becomes inapplicable, because the line segments considered separately are usually meaningless. On the other hand, if the pattern contains too many points, using the method requires large computational resources. Therefore, when restoring images, we choose the optimal of the two methods, more often giving preference to the first of them (PLS-model).

Comparison of pattern processing methods

Let's compare different processing methods, choosing as an example the pattern composed from all words beginning with one of the neighboring letters of the alphabet, R(r) or S(s) in quatrains. The initial discrete pattern is shown in Figure 3a. The Fig.3b show the result of using standard filter “Blur” in “Wolfram Mathematica” [15], which do not lead to a noticeable improvement in image quality. Fig.3c and Fig.3d present our proposed method of image reconstruction by line segments (LS-method) and the model of point light sources (PLS), respectively. It can be seen that both methods significantly improve the quality of visual perception of the original pattern. Pseudo-coloring facilitates the visual perception (Fig.3e). Finally, Fig.3f shows the manual fragment markup. We can see two human faces superimposed on each other, as well as an object resembling a cat's face in the upper right corner. We conclude that the image is sufficiently stable with respect to the method change. Herewith, the specific methods proposed by us (LS-method and PLS-model) seem to be preferred over the built-in processing method “Blur” in “Wolfram Mathematica”.

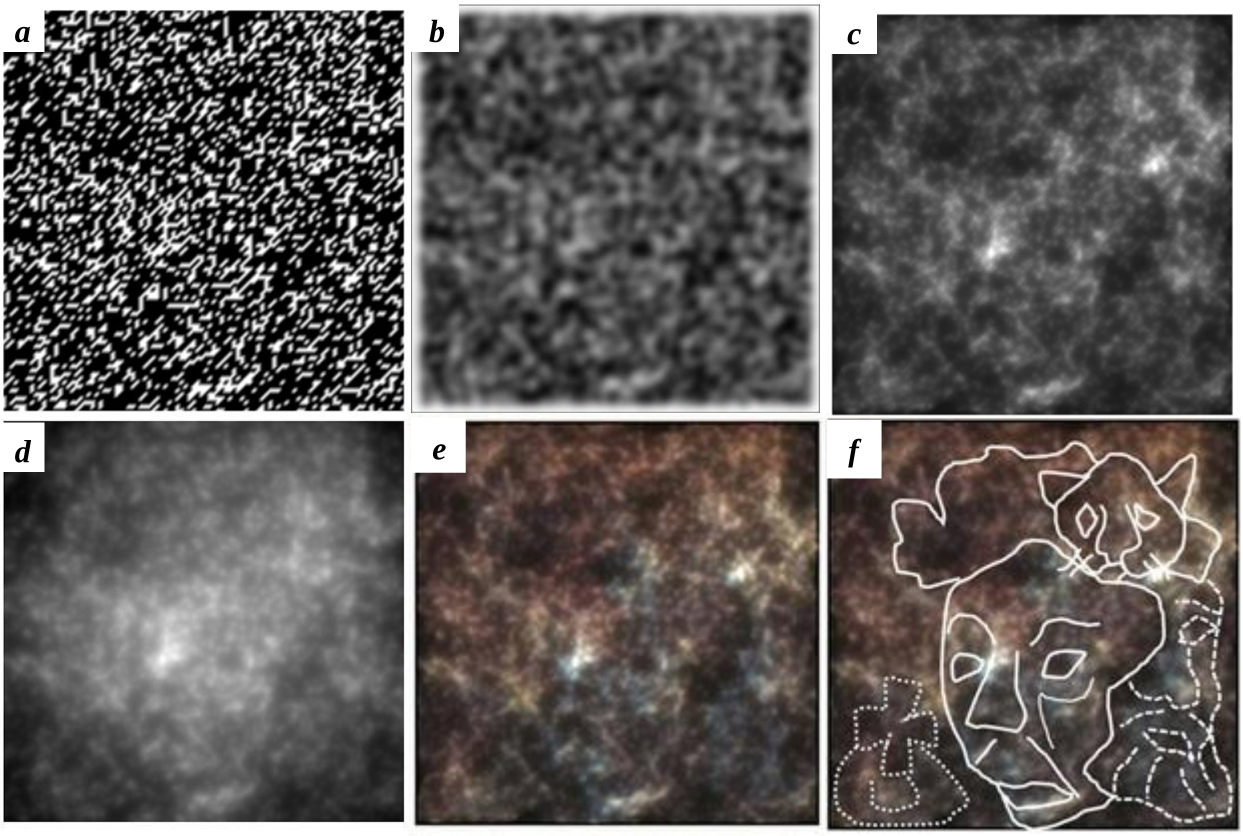

Fig.3. Comparation of pattern processing methods for the image recovered from words beginning with the neighboring letters of the alphabet R(r) or S(s) in quatrains: original pattern ***(a)***; the result of using the filter "blur" in "Wolfram Mathematica" ***(b)***; reconstruction the image by line segments (first step only, d=1, R_1=20, m=1) ***(c)***; the result of using the PLS-model (p=1, h=2.5, n=3) **(*d*)**; pseudo-coloring for the fragment (c) ***(e)***; manual fragment markup ***(f)***.

3 Results: examples of encrypted images

In most of the discovered images, we see human faces, often combined, superimposed on each other, changing from one to another when the brightness is inverted or when the picture is rotated. The point selection rule is most simple and obvious when absolutely *all* words in quatrains or in prose texts are displayed on a plane; this avoids the subjectivity associated with the first paragraph of the algorithm (see section 2.1). In this case, the image appears because different words in the texts have different lengths, which leads to the appearance of brightness gradients. Such encrypted images have been obtained both for quatrains and for prose texts ("Preface to Caesar" and "Preface to King Henry").

It also looks quite natural when all words *beginning* with a given letter of the alphabet or *containing* a given letter of the alphabet are displayed on the plane. It was also empirically established, in some cases it is necessary to combine groups of points corresponding to neighboring letters of the alphabet. We have found many such examples, showing that this technique seems to involve all the letters of the alphabet.

In addition, we found that in some cases the selection rule (the first step of the algorithm, see section 2.1) can be more complex, for example, all words containing the given letters of the alphabet in positions from first to fifth are displayed on the plane. Such examples are the most controversial, since it is in this case that the probability increases that we are dealing with pareidolic phenomena [20]. Among such images, we present only those that are characterized by good clarity.

In general, the author believes that Nostradamus created a large graphic cipher, the rules of which in some cases are simple and obvious, and in some cases remain unclear. Since we do not know the original method used by Nostradamus to transition from discrete to continuous images, the methods we proposed (Section 2.2) allow us to obtain only approximate images.

3.1 Images encrypted in quatrains

The Figure 4a shows the image formed by all capital letters present in the name "NOSTRADAMVS" (the letter “V” is always used instead of “U” in facsimile of “The Prophecies”). When constructing this image, we used the method of connecting points with line segments. We can see the face of a bearded man with a mark (the third eye?) on his forehead and a supposedly six-pointed star in the lower left corner of the square. Other details of the figure require careful interpretation and are not discussed here. Note, we filled with randomly generated points the strip corresponding to missing quatrains of the seventh century (a similar procedure will also be used in other figures without new explanations).

The Figure 4b presents the image recovered from *all* words in quatrains by the method of point light sources. In this case gradients of light density due to the fact that different words have different lengths. We see again the face of a bearded man, and upon further examination we can distinguish several more faces superimposed on each other. Most remarkably, the brightness inversion in this image results in a completely new face (Figure 4c). In our opinion, such a play of light and shadow requires a high skill of the artist.

Next, we find that this rather complex image, which has been made up of *all* the words, can be represented as a superposition of a long series of other images, for which more complicated selection rules are used. Figure 5a shows an image recovered from all words containing the letter A(a). We can see the face of a young man in a headdress resembling a hat with a cockade. The contours of the face of an adult male superimposed on it are less visible.

Figure 5b shows an image recovered from all words containing the letter O(o). You can see a fragment of the face of what appears to be a teenager (close-up of eyes and nose) with a small cross on the bridge of the nose. In Figure 5c, all words containing neighboring letters of the alphabet P(p) or Q(q) have been added to the previous pattern. The person's face now looks more mature, and in addition, the outline of another face appears as a hint in the forehead area. All three images shown in Figure 5 required a brightness inversion in the pattern (i.e. the words are displayed on the plane as dark spots on a light background).

Figure 6a shows an image obtained from all words containing the letter L(l). You can see the face of a man with a lush mustache and a small cap on the back of his head.

Figure 6b shows an image recovered from all words containing the letter R(r). We see the outlines of two faces superimposed on each other. Unlike Figure 5, these images did not require brightness inversion. At the same time, after the brightness inversion in Figure 6b, a new face appears (Figure 6c).

Figure 7a shows an image obtained from all words containing letters of the alphabet from A(a) to D(d). This drawing inherits the main features of the image shown in Fig.5a, but now the first face is present only as a hint, while the second face, on the contrary, becomes much more distinct.

Figure 7b shows the image obtained from all words containing the letters of the alphabet from E(e) to N(n). Here we see a non-human face, which may belong to an animal or a demon. When this image is rotated 90 or 180 degrees, human faces can also be seen.

Figure 7c shows the image obtained from all words containing letters of the alphabet from Q(q) to T(t). We see a portrait of a respectable elderly man in a headdress characteristic of the Middle Ages.

In all cases presented in Fig.7, the inversion of brightness in the pattern is required. Taking into account that the image obtained from all words containing the letters of the alphabet from O(o) to Q(q) was presented above (Fig.5c), we can conclude that the alphabet is divided into several intervals, each of which contains some image.

Figure 8a,b presents an image obtained from words containing letters of the alphabet from A(a) to I(i). Thus, it continues the logical chain formed from Fig.5a (words containing letters A(a)) and Fig.7a (words containing letters from A(a) to D(d)). We see that adding new letters to this sample leads again to a change in the image. Two new male faces appear. The first face is observed in the original (white on black) pattern (Fig.8a) and the second face appears after brightness inversion (Fig.8b).

Figure 8c shows an image obtained from words containing the letters Y(y) or Z(z). In this case, the pattern contains fewer points than in the previous cases. However, a continuous image appears as a result of a significant increase in the radius of the spots (R~50), replacing the points of the pattern when using the PLS model at p=0.

We also obtained images from all words containing the letter M(m); the letters M(m) or N(n); the letters U(u) or V(v); the letters of the alphabet from H(h) to J(j); from I(i) to Q(q); from P(p) to Z(z) (see Appendix). Thus, all letters of the alphabet are involved in this cipher system, where images are formed from words *containing* some letters.

We also found that the word selection rules described above are not the only ones. A large series of images is formed from words *starting* with given letters of the alphabet. Examples of the clearest images that match this rule are shown in Figures 9 and 10. All the images in Figure 9 display the words on a plane in white on a dark background, and all the images in Figure 10 require brightness inversion.

The Figure 9a shows an image recovered from words beginning with neighboring letters of the alphabet C(c) or D(d). We see a portrait of a man in a high headdress, on which the letters "Pon" are visible. This is probably a portrait of the pontiff wearing the papal tiara.

The Figure 9b presents an image constructed from words beginning with adjacent letters of the alphabet O(o) or P(p). Here we see two male faces superimposed on each other, with one eye in common.

The Figure 9c shows an image recovered from words beginning with adjacent letters of the alphabet S(s) or T(t). We can see the cheerful male face in glasses with curly hair, and the outlines of the tower to the left of this person. We should not be surprised at the appearance of glasses, since the first glasses were invented in Italy in the 13th century.

The Figure 10a presents an image constructed from words beginning with adjacent letters of the alphabet A(a) or B(b). We see the face of an elderly bearded man.

The Figure 10b presents an image recovered from words beginning with neighboring letters of the alphabet E(e),F(f),G(g) or H(h). We see the face of a young man in a helmet.

The Figure 10c shows an image obtained from words beginning with neighboring letters of the alphabet R(r) or S(s). We see a woman's face with an object (hair clip?) resembling a cat's face in the hair, in the upper right corner of the image. Note that in the absence of brightness inversion, this figure shows two male faces superimposed on each other (see Figure 3).

We also obtained images for words starting with the letter C(c); the letter F(f); the letter G(g); the letters from A(a) to O(o) (see Appendix, Fig.A1, Fig.A10a).

Thus, almost all letters are involved in this cipher system, where images are formed from words starting with one letter or another. Perhaps the absence of some letters in this system at the moment is due to the imperfection of our technique for processing patterns, which does not allow to detect some images.

Table 1 systematizes the images obtained within the framework of the cipher systems described above. Images described above are marked with “*”. The icon "?" indicates patterns for which images probably exist, but were not shown due to low quality.

However, some images do not belong to either of the two logically simple encryption systems described above, which complicates the systematization of the results. The Figure 11 present some of the images obtained by taking into account given letters in the first few positions of words. Since the average length of a word in French is about 10 letters, one would assume that the results are close to corresponding images obtained from words containing given letters (in any position of the word), which is within the previous logic. However, our analysis shows that for Figure 11, taking into account all positions in words leads to a deterioration in the quality of images, up to their complete disappearance. The reader can find more examples of this group in the Appendix (Figures A5–A8).

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	x	y	z
Words containing some letters	*																								
	*	?	?					*				*	*		*			*							
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Table 1. Images formed by words containing some letters or starting with some letters.

3.2. Images encrypted in prose texts

In the preface addressed to Caesar, we displayed as points on the plane *all* the first letters of words with the key N=123 (see formula (2)) in a qualitative analogy with Figure 4b,c. The result after processing is Figure 12a, in which we see a bearded man wearing a crown. A small cross is clearly visible in the lower left corner. After color inversion and 90 degree rotation, another male face can be seen in this drawing.

We have also displayed all the letters of the alphabet from A(a) to O(o) (i.e. about half of the letters in the text) by points on the plane with the same key N=123. The result after processing is a clear image of a human eye, placed in the center of the rectangular computational domain (Figure 12b).

In the preface addressed to King Henry, we have also displayed as points on the plane *all* the first letters of words with the key N=164 (see formula (2)). The result is an image of a snake (or a dragon) with a human face on its back (Figure 12c). After rotating 90 degrees clockwise or contraclockwise, other faces can be seen in this drawing.

We have also displayed with points on the plane all the words beginning with the letters of the alphabet from A(a) to I(i) (i.e. about half of the words in the text); the result after processing is a blurred image of the face of a bearded crowned man (Figure 13a).

Several more images can be obtained by displaying all letters from some intervals of the alphabet. For example, all letters from A(a) to L(l) form a thin male face (Figure 13b); all letters from G(g) to M(m) form two bearded male faces (Figure 13c).

Note that when constructing images based on *prose* texts, difficulties may arise due to the fact that the coordinates of words are determined with an error depending on the edition of «The Prophecies» (we followed the edition of 1568), typos, counting spaces and punctuation marks, and so on. These problems for a specific version of the text can be solved, first of all, by calibrating the image by varying the number N, which for other editions may differ slightly from the one we specified.

Fig.4. The image recovered from all capital letters in quatrains present in the name "NOSTRADAMVS" using LS-method (d=2.5, m=1, s_1=s_2=10^{-2}, R_1=90, R_2=7) and subsequent color inversion ***(a)***, from all words in quatrains using PLS-model (p=1.5, h=2.5, n=20); ***(c)*** the result of brightness inversion in Fig.4b with a subsequent new pseudo-coloring. Manual fragment markup is at the bottom.

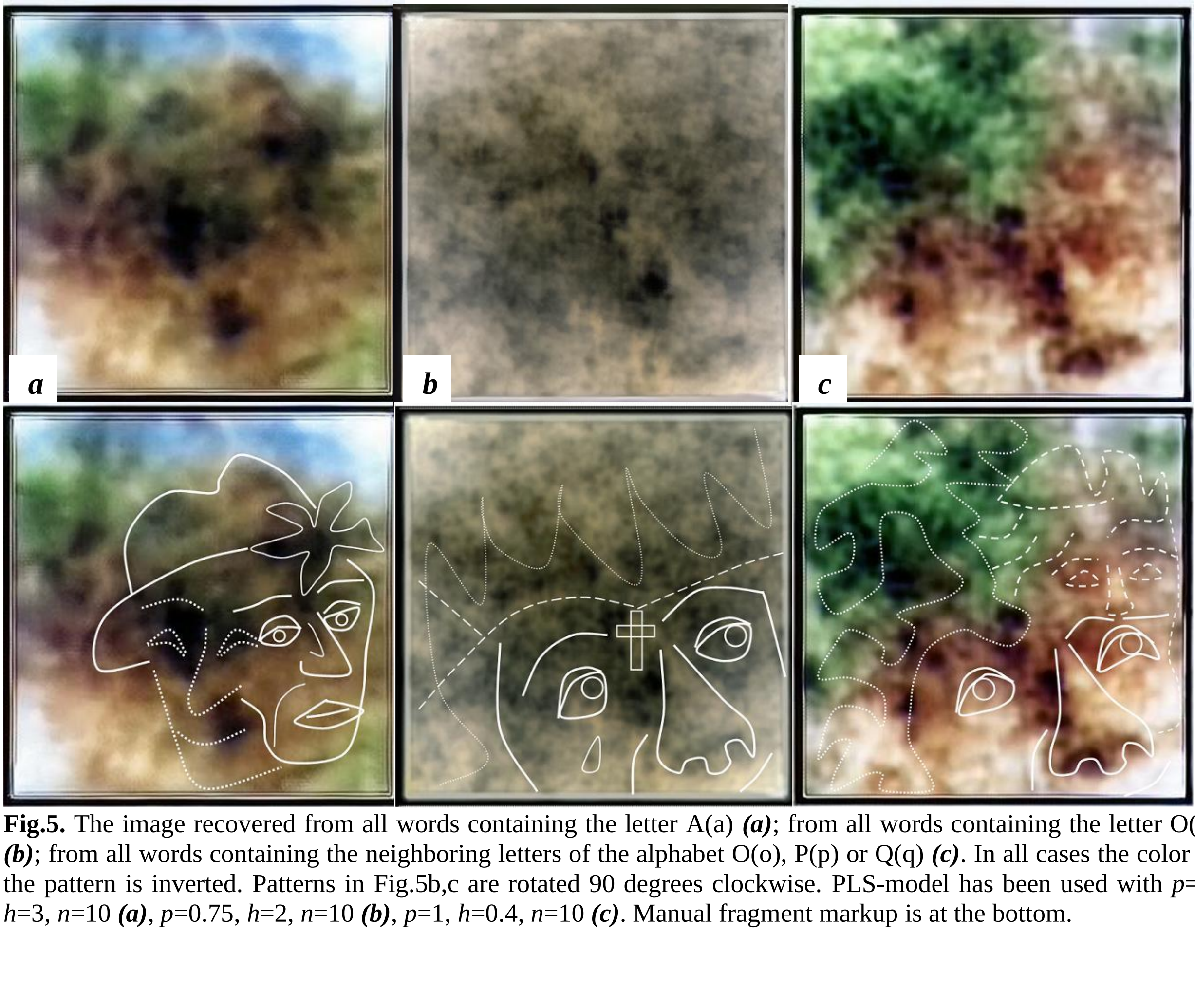

Fig.5. The image recovered from all words containing the letter A(a) ***(a)***; from all words containing the letter O(o) ***(b)***; from all words containing the neighboring letters of the alphabet O(o), P(p) or Q(q) ***(c)***. In all cases the color of the pattern is inverted. Patterns in Fig.5b,c are rotated 90 degrees clockwise. PLS-model has been used with p=1, h=3, n=10 ***(a)***, p=0.75, h=2, n=10 ***(b)***, p=1, h=0.4, n=10 ***(c)***. Manual fragment markup is at the bottom.

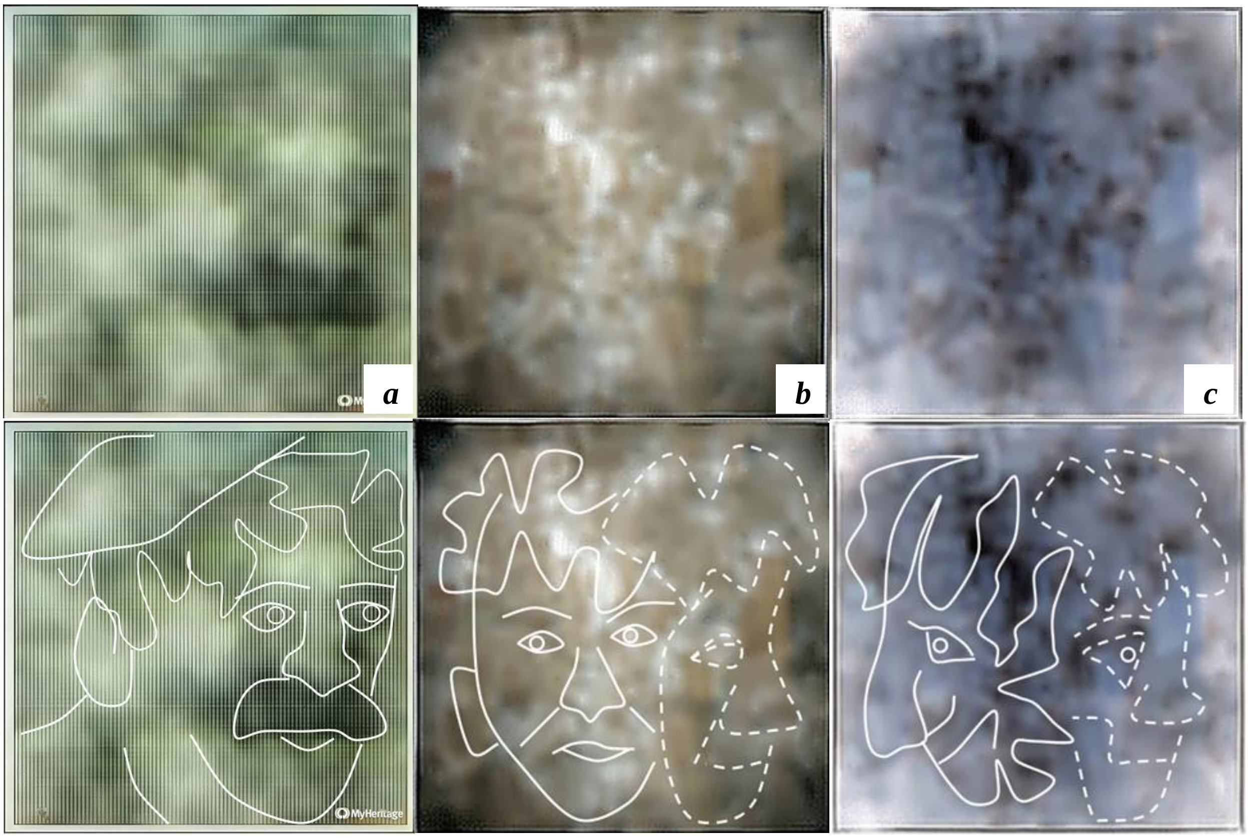

Fig.6. The image recovered from all words containing the letter L(l) using PLS-model (p=0.5, h=3.3, n=10) ***(a)***; from all word containing the letter R(r) using PLS-model (p=1, h=2.5, n=10) with rotation the pattern 90 degrees contraclockwise ***(b)***; the previous image after color inversion ***(c)***. Manual fragment markup is at the bottom.

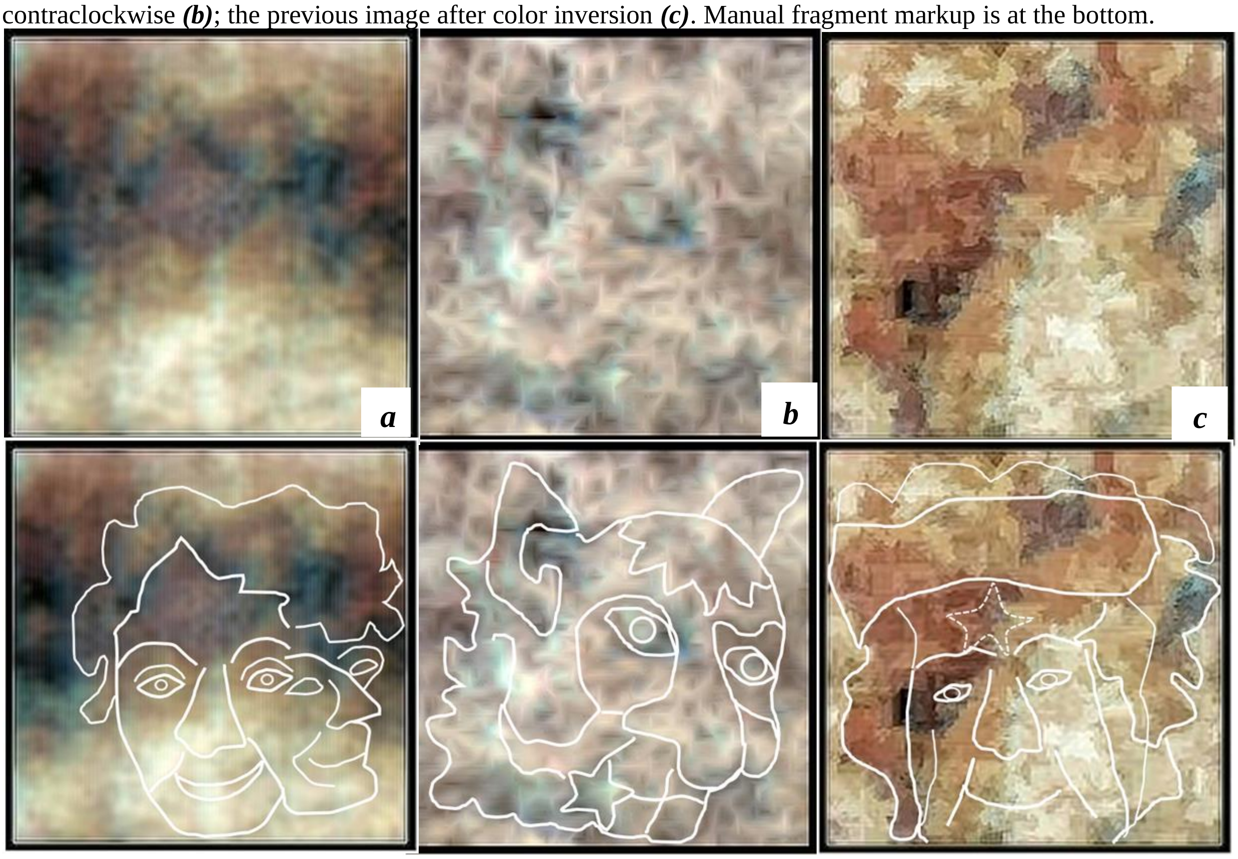

Fig.7. The image recovered from words containing the neighboring letters of the alphabet from A(a) to D(d) using PLS-model (p=0.5, h=1.7, n=1) ***(a)***; from E(e) to N(n) using PLS-model (p=0.7, h=1, n=1) with the pattern rotated 90 degrees contraclockwise ***(b)***; from Q(q) to T(t) using PLS-model (p=0.5, h=0.7, n=1) with the pattern rotated 180 degrees ***(c)***. In all cases the color of the pattern is inverted. Manual fragment markup is at the bottom.

Fig.8. The image recovered from words containing the letters of the alphabet from A(a) to I(i) using PLS-model (p=1, h=1, n=1) ***(a)***; the previous image after color inversion ***(b)***; the image recovered from words containing the letters Y(y) or Z(z) using PLS-model (p=0, each point is replaced by a circle of radius R=50, and when the circles are superimposed, their brightnesses are summed) ***(c)***. Manual fragment markup is at the bottom.

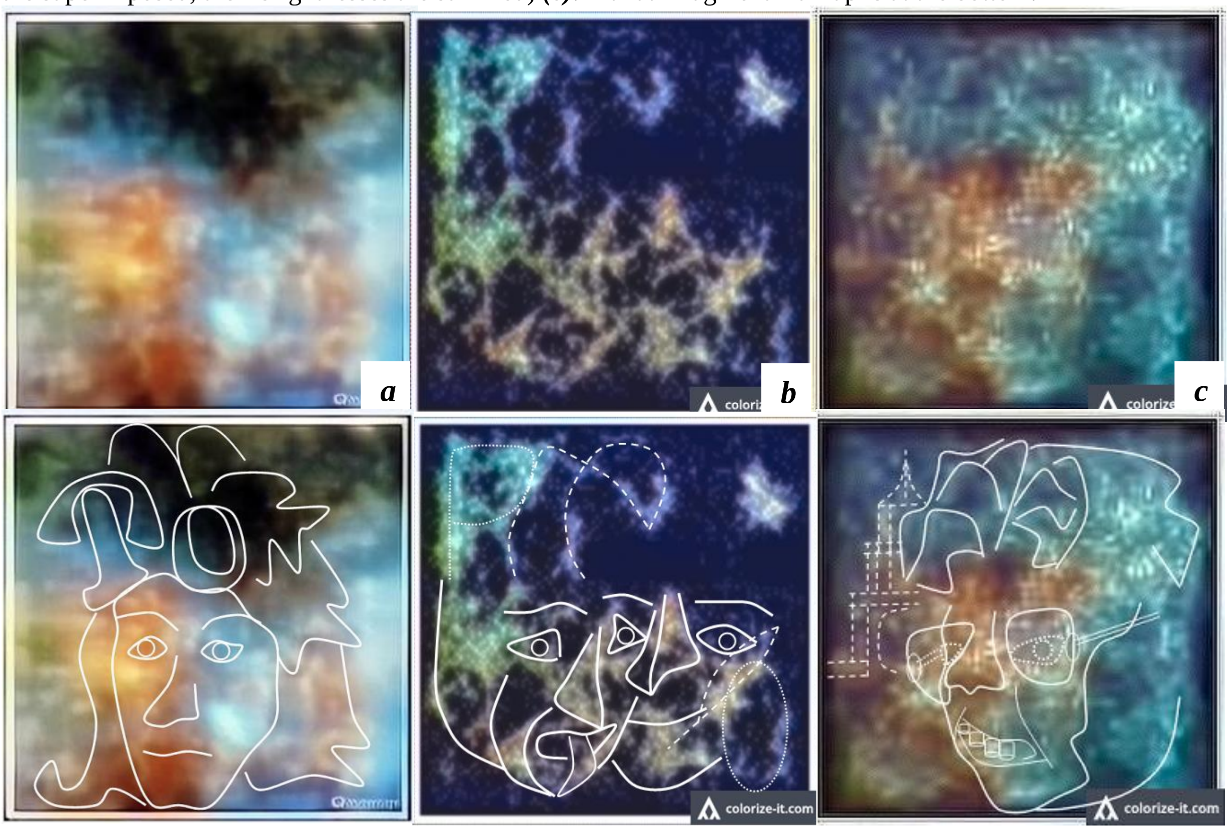

Fig.9. The image recovered from words beginning with neighboring letters of the alphabet C(c) or D(d) using PLS-model (p=0.6, h=1.7, n=10) ***(a)***; from words beginning with neighboring letters of the alphabet O(o) or P(p) using LS-method (d=1, m=1, R_1=20, R_2=4, s_1=0.25, $s_2=10^{-2}$) ***(b)***; from words beginning with neighboring letters of the alphabet S(s) or T(t) using LS-method (d=1, m=1, $s_1=s_2=10^{-2}$, R_1=20, R_2=10) ***(c)***. Patterns in Fig.9a is rotated 180 degrees. Manual fragment markup is at the bottom.

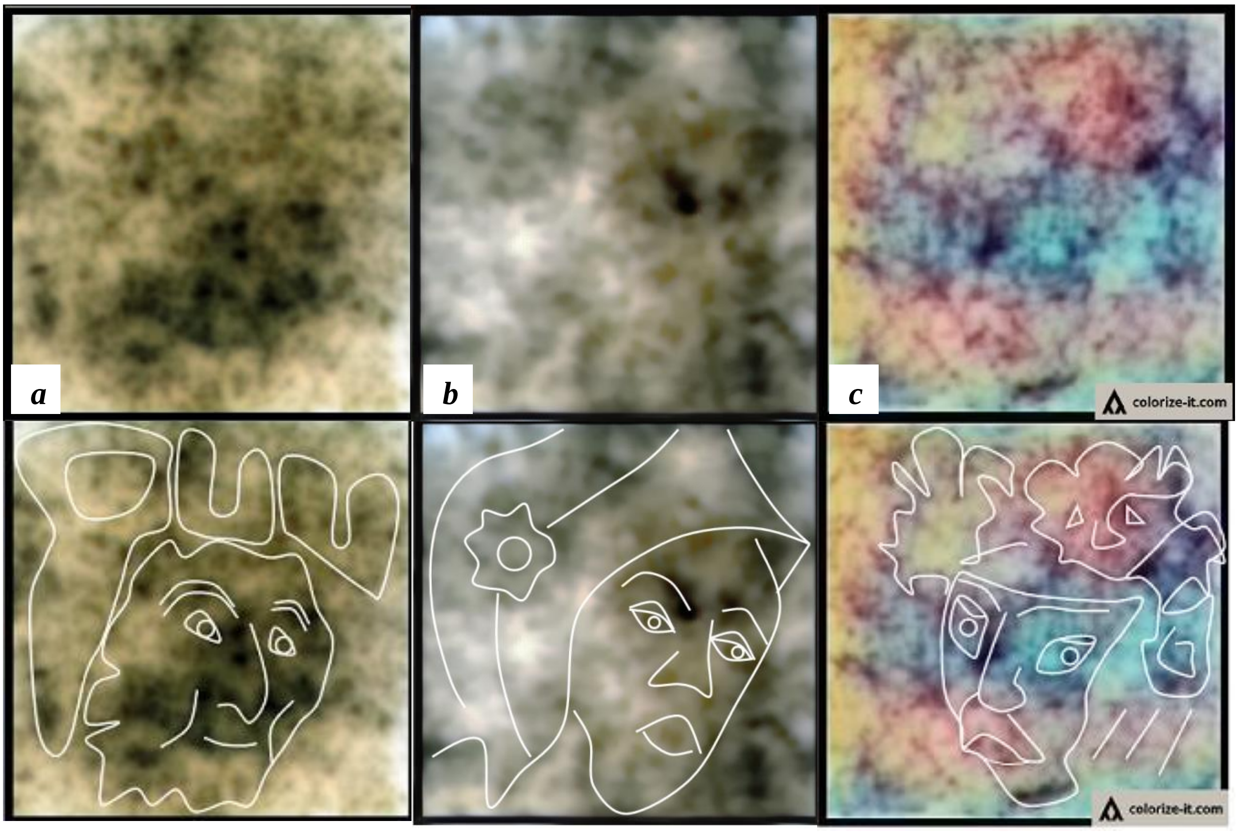

Fig.10. The image recovered from words beginning with neighboring letters of the alphabet A(a) or B(b) using PLS-model (*p*=0.5, *h*=1.7, *n*=10) with color inversion and rotation 90 degrees clockwise ***(a)***; from words beginning with letters from E(e) to H(h) using PLS-model (*p*=0.75, *h*=2, *n*=10) with color inversion and rotation 90 degrees contraclockwise ***(b)***; the result of color inversion in the Fig.3c with subsequent pseudo-coloring ***(c)***.

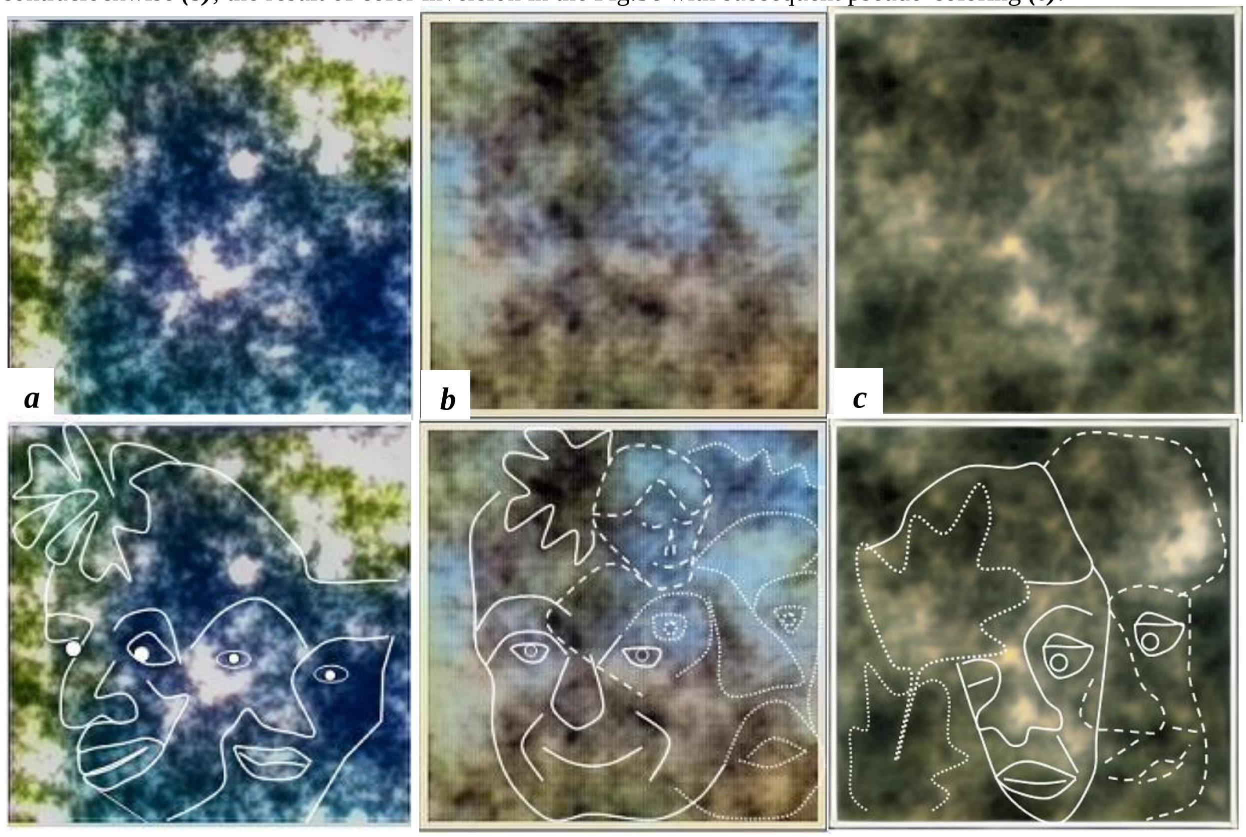

Fig.11. The image recovered from words containing the neighboring letters of the alphabet E(e) or F(f) in the first, second or third positions, using PLS-model (*p*=1.5, *h*=2.5, *n*=10) ***(a)***; from words containing the letters of the alphabet from C(c) to F(f) in the 1,2,3,4 or 5 positions, using PLS-model (*p*=0.6, *h*=1.8, *n*=5) ***(b)***; from words containing the letters of the alphabet from P(p) to S(s) in the 1,2,3,4 or 5 positions, using PLS-model (*p*=0.6, *h*=1.8, *n*=5) ***(c)***. Manual fragment markup is at the bottom.

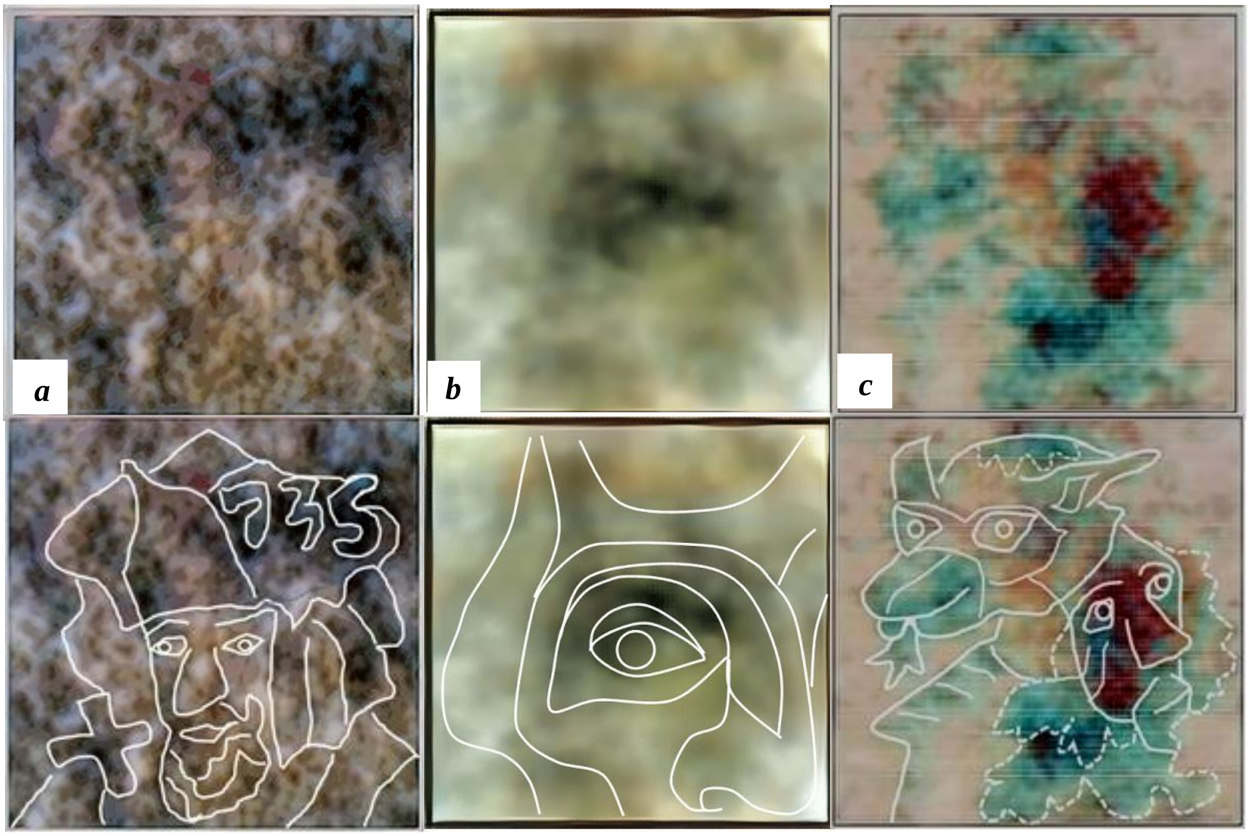

Fig.12. The image recovered from all first letters of the words in the preface to Caesar with rotation 90 degrees contraclockwise ***(a)***; the image recovered from all the letters of the alphabet from A(a) to O(o) in the preface to Caesar ***(b)*** using PLS-model (p=1, h=2, n=10) with a grid size 125x123. The image recovered from all first letters of the words in the preface to King Henry using PLS-model (p=0.5, h=2, n=10) with a grid size 167x164 ***(c)***. Manual fragment markup is at the bottom.

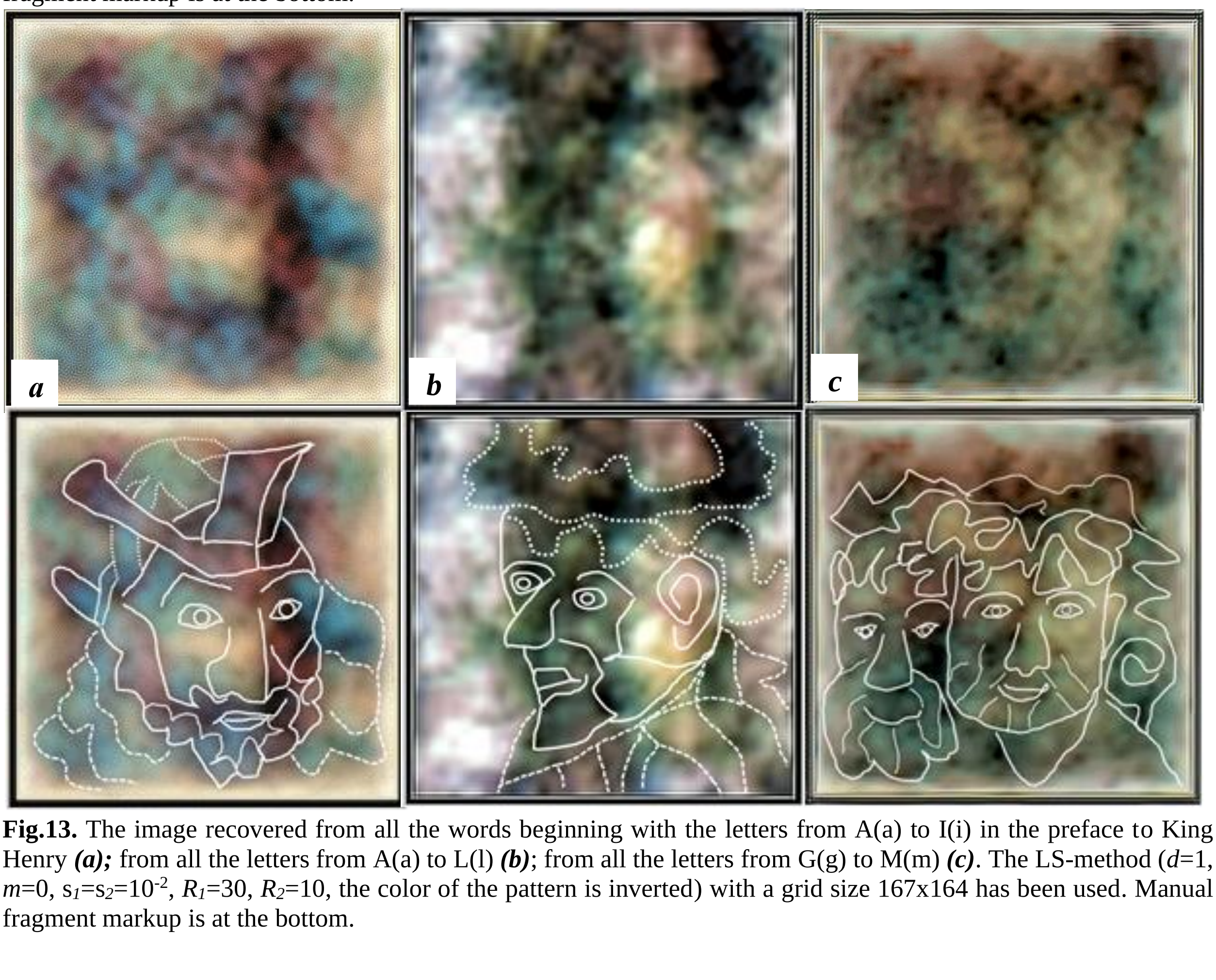

Fig.13. The image recovered from all the words beginning with the letters from A(a) to I(i) in the preface to King Henry ***(a);*** from all the letters from A(a) to L(l) ***(b)***; from all the letters from G(g) to M(m) ***(c)***. The LS-method (d=1, m=0, s_1=s_2=10^{-2}, R_1=30, R_2=10, the color of the pattern is inverted) with a grid size 167x164 has been used. Manual fragment markup is at the bottom.

4 Discussion

4.1 Graphic cipher or pareidolia?

It is well known, the human mind has a propensity to detect the outlines of faces among the random noise [20]. This effect, called pareidolia, indicates the high importance of face recognition in a human life. Apparently, the reason of pareidolia is the ability of the brain to quickly analyze a large amount of information, highlighting the contours of significant objects, and neglecting defects. Herewith, the contours of significant objects are realized in large volumes of noise due to natural random factors. Therefore, the problem is not to find a visible or mathematical difference between a real image with defects and a pareidolic image, but rather to evaluate the probability of random realization of image contours in random noise.

A famous example of pareidolia is the face of the sphinx on Mars [21], which demonstrates a few differences from the cipher we are considering.

(1) The image features for the “Martian sphinx” are less pronounced than in our images. It is no coincidence that it is called the “sphinx”, because indeed the face is greatly distorted and bears little resemblance to a human.

(2) The “sphinx” is perhaps the single pareidolic effect in the infinite variety of the Martian landscape. It is not surprising that among a wide variety of forms, contours resembling a fantastic face can be found. In contrast, in “The Prophecies” of Nostradamus an ornament with signs of artificial origin is observed almost everywhere.

(3) Unlike pareidolic effects, Nostradamus's graphic cipher has signs of consistency. For example, displaying *all* words on a plane leads to the appearance of images for both quatrains (Fig.4b,c) and prose prefaces (Fig.12a,c). Figures 5–10, obtained from words in quatrains, have a fairly high level of systemic organization, since all letters of the alphabet are involved in the cipher system. Moreover, the alphabet can be divided into non-overlapping intervals, in each of which an image is found (see the fifth line of Table 1).

(4) An important qualitative difference between recovered images and pareidolic phenomena is the appearance of twin images when the color is inverted (Fig.3c and Fig.10c, Fig.4b and Fig.4c, Fig.6b and Fig.6c, Fig8a and Fig.8b) or when the pattern is rotated (see, for example, Fig.A2b and Fig.A2c, Fig.A3, Fig.A9b and Fig.A9c, Fig.A10b and Fig.A10c in Appendix). Indeed, since the pareidolic image is a combination of light spots that accidentally took on a familiar shape, the probability of realizing a new familiar shape when a color is inverted or when the pattern is rotated seems small. On the contrary, in the graphic cipher of Nostradamus, we encountered these features in many cases. Only a few examples have been discussed. Further examples may be found by the reader himself, using the figures provided.

Qualitative arguments refer to the problem as a whole and do not negate the usefulness of mathematical evaluations for specific images. The discovery of mathematical criteria for images could contribute to more efficient processing of patterns. Therefore, the involvement of specialists in the field of pattern recognition and image processing in this topic can be very fruitful.

4.2. Criterion of pattern connectivity

A necessary condition for a graphic cipher is an ordered arrangement of the points of the pattern, which, presumably, should show a tendency to form lines (connectivity). Let us define the degree of connectivity of a pattern as follows. We choose a point I of the pattern and count the number of points that are at a distance no more than R from the initial point. We call them the first neighbors of point I. Let's perform a similar procedure for all found first neighbors, and then exclude from the resulting list those points that are already in the list first neighbors. We call the resulting list the second neighbors of point I. We continue the described procedure until the neighbor list of the next level becomes empty. The combined list of neighbors of all levels we call the network of point I, and the number of elements in it we call the size of the network. Obviously, the size of the network of point I depends on the selected distance R. By summing up the sizes of the networks for all points of the pattern and dividing the resulting sum by the number of points in the pattern, we obtain the average size of the network, which characterizes the connectivity of the pattern. Let us generate a sufficient number (for our purposes, 1E+05…1E+06 is quite sufficient) of random patterns of the same size, and for each of them, we calculate the average size of the network. The fraction P of random patterns for which the average size of the network is greater than or equal to the average size of the network of the initial pattern represents an estimate of the probability of the random realization of the initial pattern (according to the connectivity criterion) at a given R. By repeating the described procedure for different R, we can plot the dependence P(R). By definition, the function P(R) tends to 1 in the limit of both small and large R, and has a minimum at some intermediate R. We take the value of this minimum, P_{min}, as an estimate of the probability of the random realization of the pattern according to the connectivity criterion.

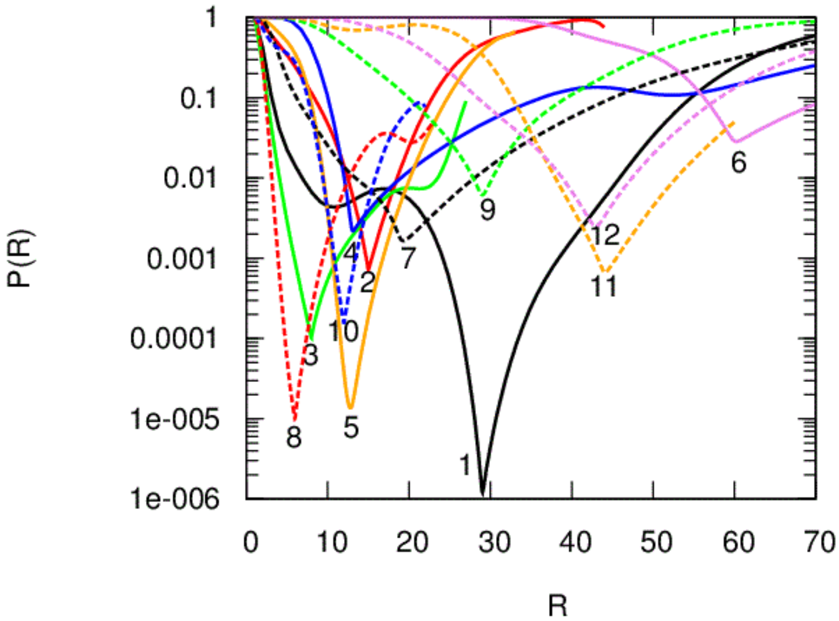

Fig.14. Smoothed probability curves of the random realization P(R) for patterns composed of words with roots (1) “arab”, (2) “contre”, (3) “ciel”, (4) “larm”, (5) “loin”, (6) “bras”, (7) “malins”, (8) “est”, (9) “gaulois”, (10) “dedans”, (11) “deceus”, (12) “arc” in quatrains (grid size is 200x200).

Figure 14 shows the P(R) graphs obtained for patterns corresponding to given words in quatrains (patterns were composed of words that occur at least five times, see also Figure 1). It can be seen that the value of P_{min} in some cases is of the order of 1E-05. This seems remarkable, because the freedom to choose patterns in our experiment is limited (the material of the quatrains allows us to compose only a few hundred such patterns).

To assess the effect of the freedom to choose patterns, we compared the P_{min} values in two samples. The first sample was made up of 100 randomly selected patterns corresponding to the words in the quatrains. The second sample is made up of randomly generated patterns with similar sizes. For both samples, the P_{min} values corresponding to the patterns were calculated. In the sample of random patterns, P_{min} dropped below 0.01 in ten cases, with its lowest value being 0.003. In the sample of patterns corresponding to the words in quatrains, the value P_{min}<0.01 occurred 28 times (moreover, the smallest value P_{min}~1E-05 was realized twice). The probability of such an event can be estimated using the Bernoulli formula p(k)=(n!)/(k!(n-k)!)(p^k)(1-p)^(n-k), where n=100 (number of “trials” corresponds to the number of patterns in the sample), k=28 (number of realizations of an “interesting result”), p=0.1 (estimation of the probability of realizing an “interesting result” in a single trial, based on random samples). This gives p(28)~3E-07, which is the estimate of the random realization of our result (contributions to this estimate from situations k>28 are negligibly small).

Thus, it can be considered statistically established that the words in the "Prophecies" of Nostradamus are not randomly arranged. This statement seems to be a necessary condition for a graphic cipher. However, strictly speaking, it is not a sufficient condition, because the words in the text may not be located randomly for other reasons. One such reason may be related to the requirements of rhyme in a poetic text, resulting in a short-range order of pattern points. Such a short-range order is negligible if patterns are composed of specified words and contain a relatively small number of points (less than 100), as in the described experiment. However, if patterns composed of given letters are considered, then the short-range order resulting from the requirements of rhyme may be significant. Another reason for the non-random arrangement of points may be related to the semantic content of the text, leading to some long-range order of the points. So in a narrative work, the name of the hero may first appear in the middle of the text, and then be used everywhere, leading to some "connectivity" of the pattern at large R. The counterargument to this remark is the fact that Nostradamus's quatrains are usually considered semantically disconnected, so that the integrity of the narrative is missing.

4.3 How did Nostradamus create twin images embedded in each other - white on black and black on white?

As already noted, for many encrypted images, color inversion leads to the appearance of a new (twin) image. The creation of such images requires a certain skill of the artist, and also involves the use of special techniques. A possible method for creating twin images (white on black and black on white) is illustrated in Figure 15. Light falls on a sheet of dark translucent paper. The first image is created with opaque white paint on dark paper and is viewed by the artist in a direction of the light stream. The inverse image occurs when looking at the sheet in a direction opposite to the light stream. In this case, the areas painted over with opaque white paint turn out to be darker than the background. A qualitatively similar, but more advanced technique could be painting with opaque white paint on glass. The result is the original twin image, which will be encrypted in the text in the next step.

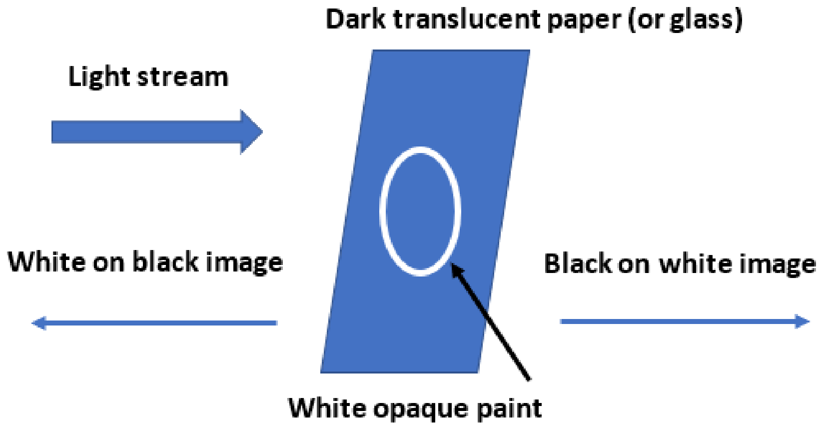

Fig.15. The supposed method for constructing twin images (white on black and black on white).

4.4 How did Nostradamus get continuous images from dotted ones?

The image encrypted in the text is a set of points. Visual perception of such discrete images in most cases is difficult or impossible. To transform discrete images into continuous ones, we have used computing resources that were not available in the 16th century. Therefore, it is necessary to find the original technique used by the artist. We assume that Nostradamus used a simple device for such processing of patterns, which is schematically presented in the Figure 16. Light from the source passes through a screen with holes (this is dotted image), then the light is scattered in the fog, and finally falls on the second screen, where a continuous image appears. In the area of intersection of light spots, their brightness is summed up. The scattering function depends on the characteristics of the light source, on the size and shape of the holes on the first screen, and on the properties of the fog. Since we do not know these parameters, we find the scattering function empirically. We believe that the insufficiently high quality of a number of obtained images is primarily due to the fact that the true light scattering function remains unknown at the moment.

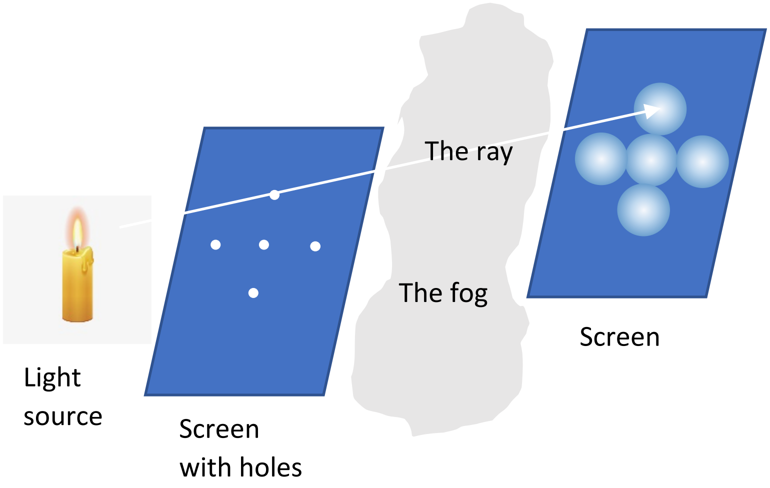

Fig.16. The supposed method used by Nostradamus to transform discrete images into continuous ones.

4.5 Cipher of Nostradamus in a historical context

By the time “The Prophecies” were published (1555–1568), the most famous encryption method was “scytale cipher” [12], in which the tape is wound on a cylinder, and text is written along the axis of the cylinder. After removing the cylinder, a set of letters remains on the tape, which seems random. The disadvantage of this method is that a meaningless sequence of letters clearly signals the presence of a scytale cipher, for decryption of which it is only necessary to find the correct radius of the cylinder.

In the 16th century, interest in developing more promising encryption methods grew in Europe. So in 1553, that is almost simultaneously with the publication of "The Prophecies" of Nostradamus, the Italian cryptologist Bellaso proposed an important modification of cipher methods [22]. The text encrypted with the Bellaso cipher still looks like a random sequence of letters, however, to decrypt it, it is not enough to choose the step value (cylinder radius), but you need to know the sequence of steps determined by the keyword. Another line of thought is reflected in the “Steganography” of Trithemius [23]. This manuscript was written in 1499, and distributed in handwritten versions; its first partial publication was made only in 1606. When using steganography techniques, an uninformed reader does not suspect that he is dealing with an encrypted message, because hidden information is embedded into plain text. Some techniques of Trithemius cipher was only recently understood [24].

The graphic cipher of Nostradamus occupies an intermediate position between the two mentioned approaches. Indeed, the cipher technique in prosaic prefaces is mathematically similar (described by the same simple formulas) to scytale cipher, where after “winding” the text on a cylinder, you can “cut” it along the cylinder axis to receive the decrypted message on a rectangular sheet. The difference is that in the prophecies of Nostradamus this procedure results in a picture instead of a text, because the selected letters do not form words, but figures on the plane. At the same time, as in the case of steganography, an uninformed reader doesn’t know he is dealing with an encrypted message.

The escape from prosaic texts to numbered quatrains is a logical next step in the methodology development, designed to transmit encrypted images in a clearer form due to the permanent refinement of coordinates along the text. It is in this case that you can encrypt a fairly complex and specific image. Note, the presence of a graphic cipher provides a simple explanation of quatrains with a non-prophetic content. Indeed, although such quatrains do not have predictive meaning, they serve as useful building material for images.

Since Nostradamus offers this method for the first time, he is at the forefront of the scientific thought of his time. Therefore, it made sense for him to encrypt in this way some formal message, for example, the image of the human eye (see Fig.12b). Already this fact would prove the authorship of Nostradamus in the development of a new promising method of steganography. However, this does not exclude that Nostradamus wanted to convey a specific message to posterity. In this case, it is necessary to identify the faces in the figures, but unfortunately, at the moment this is problematic. It seems that the artist's propensity for surrealism in a manner similar to the painting of the Italian Renaissance artist Giuseppe Arcimboldo (1528–1593) [25] (for example, using overlapping images) conflicts with the idea of transmitting specific information. At the same time, poor image quality may be due to imperfections in our pattern processing methods. Indeed, the original procedure is unknown, and the use of our methods for processing patterns leads only to approximate images.

In conclusion, we will discuss the life context that could motivate Nostradamus to create the graphic cipher. Perhaps, this idea came to Nostradamus when working on a translation of "Hieroglyphica" by Horapollo, that is, ten years before the first publication of the prophecies [26]. The content of Gorapollo's text is a very free interpretation of Egyptian hieroglyphs, including numerous images of people, animals and birds. It is easy to imagine that being impressed by the world of mysterious symbols on ancient monuments, Nostradamus decided to create his own system of mysterious graphics. On the other hand, Nostradamus was not a painter. Only the watercolors of the "papal prophecy" known [27], attributed to Nostradamus, most likely, by mistake. Therefore, it cannot be ruled out that Nostradamus encrypts the drawings of another artist, not his own.

It seems to us noteworthy the quatrain 3-94, often interpreted as Nostradamus prediction of deciphering "The Prophecies" 500 years after publication [26]: *"For five hundred years more one will keep count of him / Who was the ornament of his time: / Then suddenly great light will he give, / He who for this century will render them very satisfied".* If our assumption is correct, the work of the predictor is likened here to some kind of "ornament", i.e. a set of patterns on which you need to "shed light" in the right way.

5 Conclusion

Under the cover of a foggy predictive text, Nostradamus created a large graphic cipher, wherein the position of words and letters carries information about image elements. Approximate methods for recovering encrypted images were proposed, and mostly drawings of human faces, made in a style reminiscent of surrealism, were discovered. The results obtained need to be independently verified. Finding more appropriate methods to recover encrypted images is a relevant, but non-trivial, mathematical task. Clarification of the meaning of the obtained images is an urgent problem.

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Compliance with Ethical Standards

Funding: not applicable. The article was written by the author in his free time.

Ethical approval: this article does not contain any studies with human participants or animals performed by any of the authors.

Author declares no conflict of interest.

Appendix. Additional recovered images

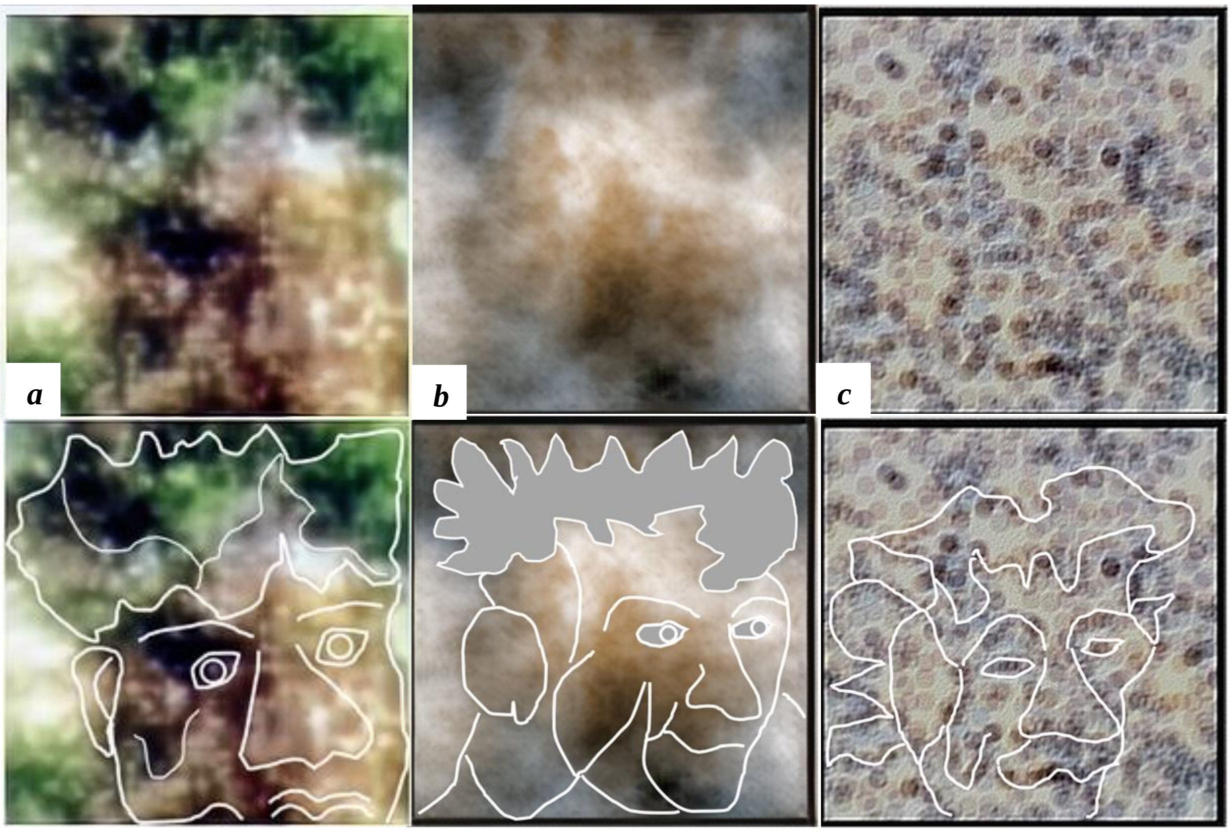

Fig.A1. The image recovered from words beginning with the letter C(c) using PLS-model (p=0.5, h=1, n=5) ***(a)***; from words beginning with the letter F(f) using PLS-model (p=0, each point is replaced by a circle of radius R=50, and when the circles are superimposed, their brightnesses are summed) ***(b)***; from words beginning with the letter G(g) using PLS-model (p=0, each point is replaced by a circle of radius R=6) ***(c)***. Manual fragment markup is at the bottom.

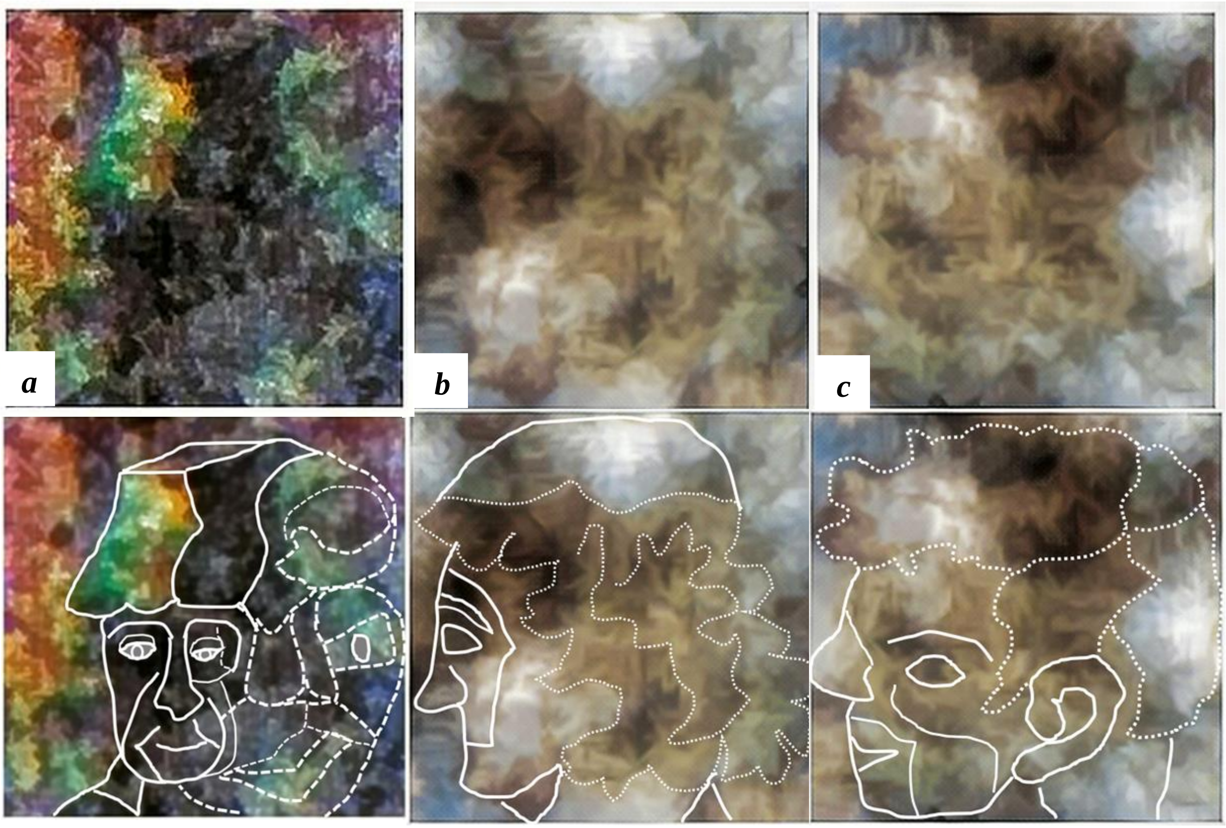

Fig.A2. The image recovered from words containing the letter M(m) using PLS-model (p=0.75, h=1, n=1) with pattern rotated 90 degree contraclockwise ***(a)***; from words containing the letters of the alphabet from I(i) to L(l) using PLS-model (p=0.5, h=1, n=1) with pattern rotated 180 degree ***(b)***, 90 degree contraclockwise ***(c)***. Manual fragment markup is at the bottom.

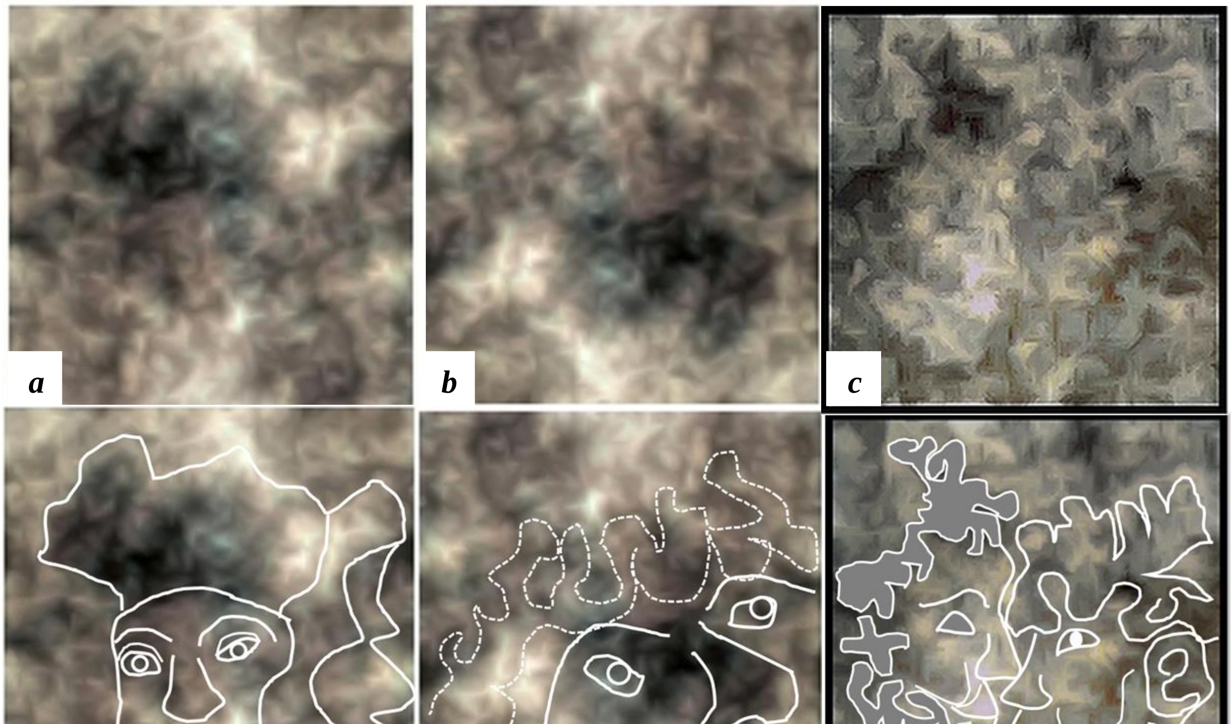

Fig.A3. The image recovered from words containing the letter M(m) or N(n) using PLS-model (p=0.5, h=1, n=1) ***(a)***; the same image after rotating 180 degree ***(b)***; the same image after rotating 90 degree contraclockwise, brightness inversion and recoloring ***(c)***. Manual fragment markup is at the bottom.

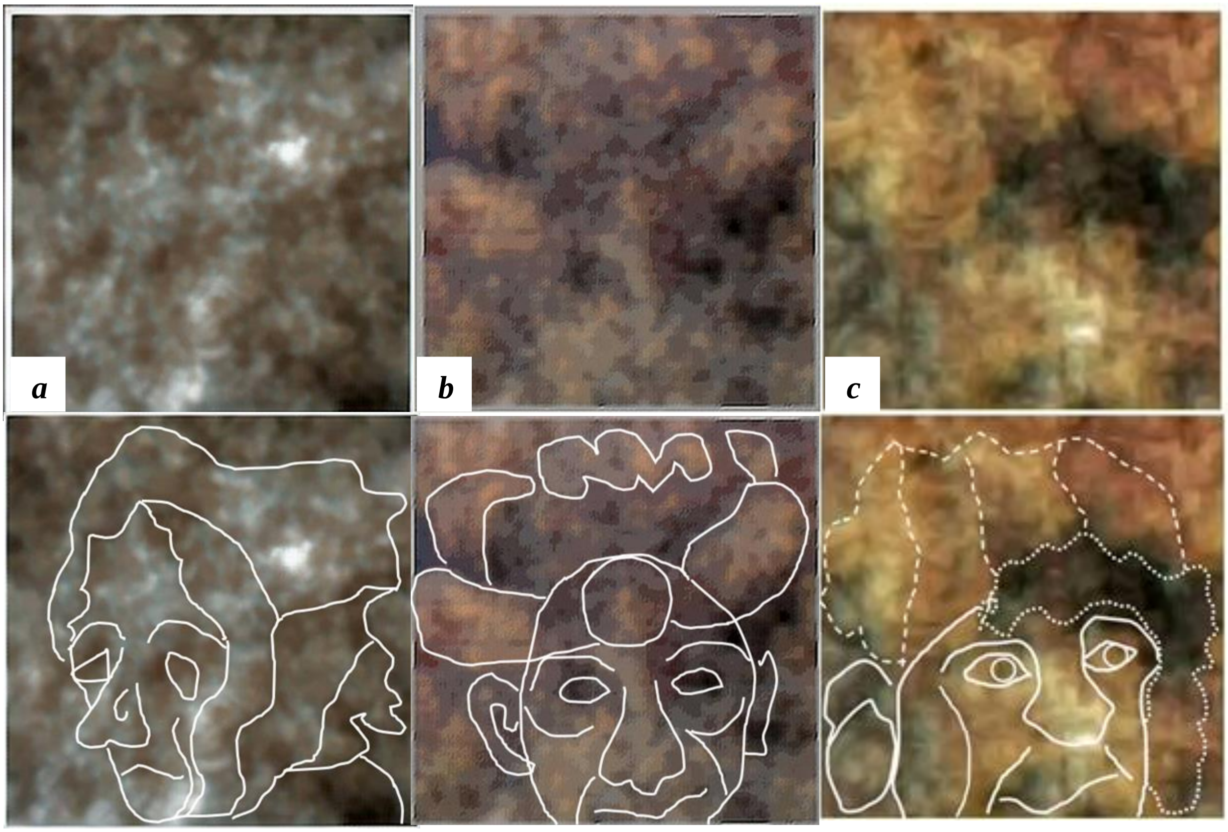

Fig.A4. The image recovered from words containing the letters of the alphabet from H(h) to J(j) using PLS-model (p=0.75, h=2.5, n=10) ***(a)***; from words containing the letters of the alphabet from I(i) to Q(q) using PLS-model (p=0.6, h=1.7, n=10) ***(b)***; from words containing the letters of the alphabet from P(p) to Z(z) using PLS-model (p=0.5, h=0.5, n=1) ***(c)***. Manual fragment markup is at the bottom.

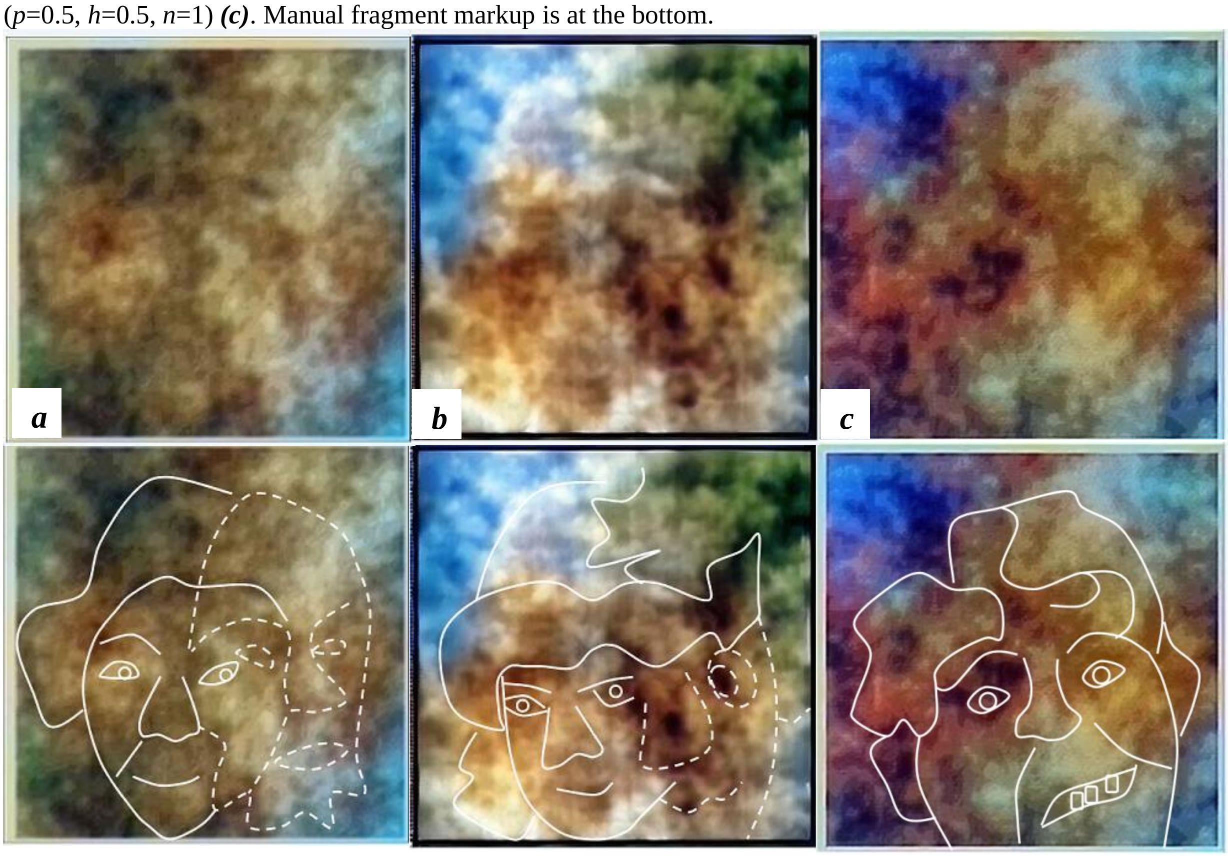

Fig.A5. The image recovered from words containing the letters of the alphabet from I(i) to S(s) in the third position ***(a)***; the result of brightness inversion of previous pattern with a subsequent recoloring ***(b)***; the image recovered from words containing the letters of the alphabet from O(o) to S(s) in the third position ***(c)***. All patterns are rotated 90 degree clockwise. The PLS-model has been used (p=0.5, h=1.7, n=10). Manual fragment markup is at the bottom.

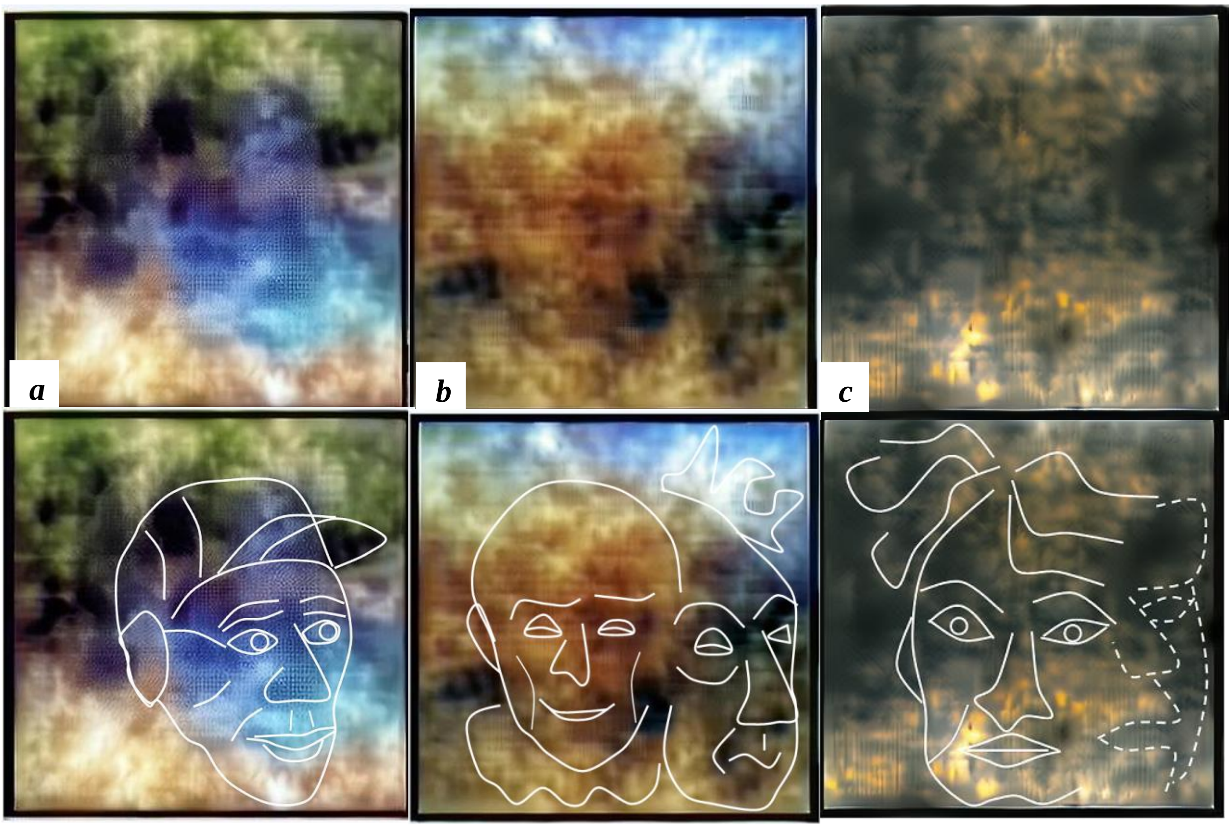

Fig.A6. The image recovered from words containing the letters of the alphabet from A(a) to E(e) in the 1 or 2 positions using PLS-model (p=0.6, h=1.7, n=10) with color inversion ***(a)***; the previous image is rotated 180 degrees and recolored ***(b)***; the image recovered from words containing the letters of the alphabet from A(a) to D(d) in the 1,2,3,4 or 5 positions, using PLS-model (p=0.6, h=1.7, n=10) [compare with Fig.7a!] ***(c)***. Manual fragment markup is at the bottom.

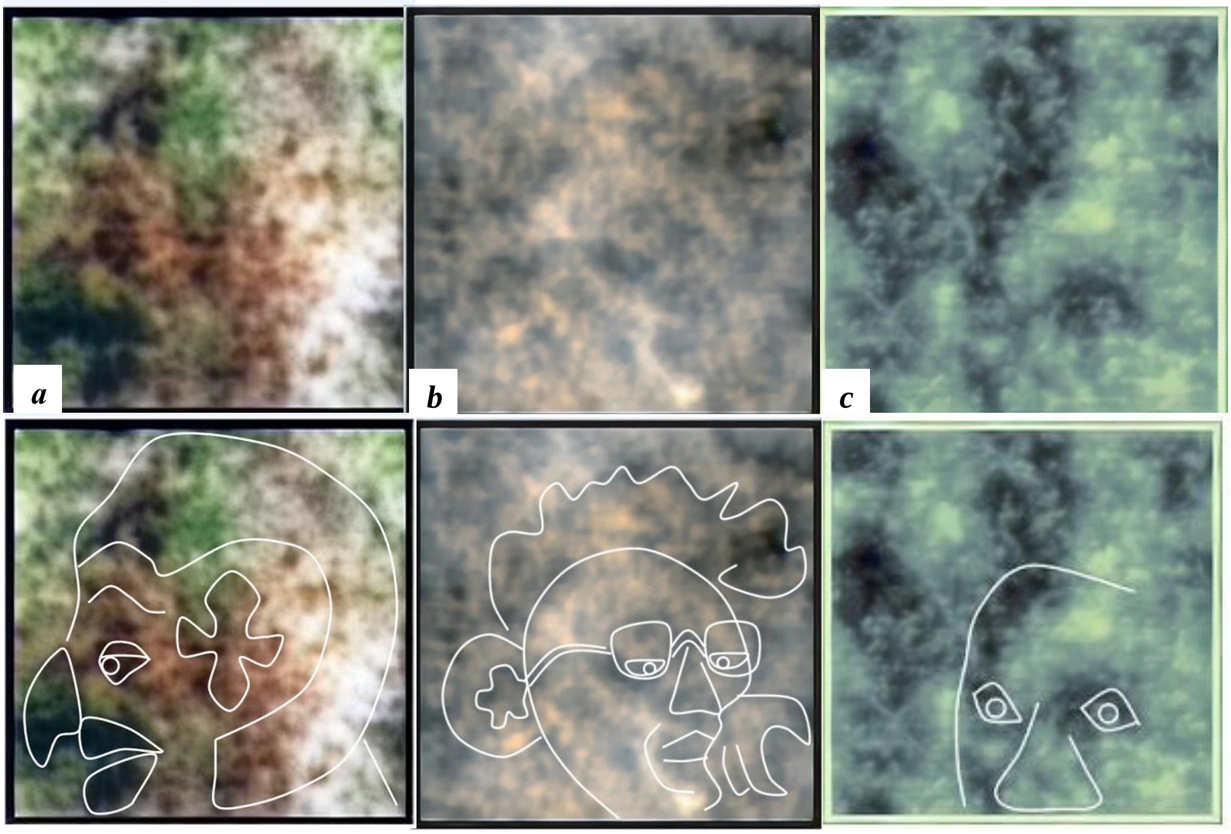

Fig.A7. The image recovered from words containing the neighboring letters of the alphabet A(a) or B(b) in the first or second positions with color inversion and rotation 90 degrees contraclockwise ***(a)***; from words containing the letters of the alphabet C(c)–F(f) in the 1,2 or 3 positions with color inversion ***(b)***; from words containing the letters of the alphabet T(t)–V(v) in the first or second positions ***(c)***. The PLS-model (p=0.6, h=1.7, n=10) has been used.

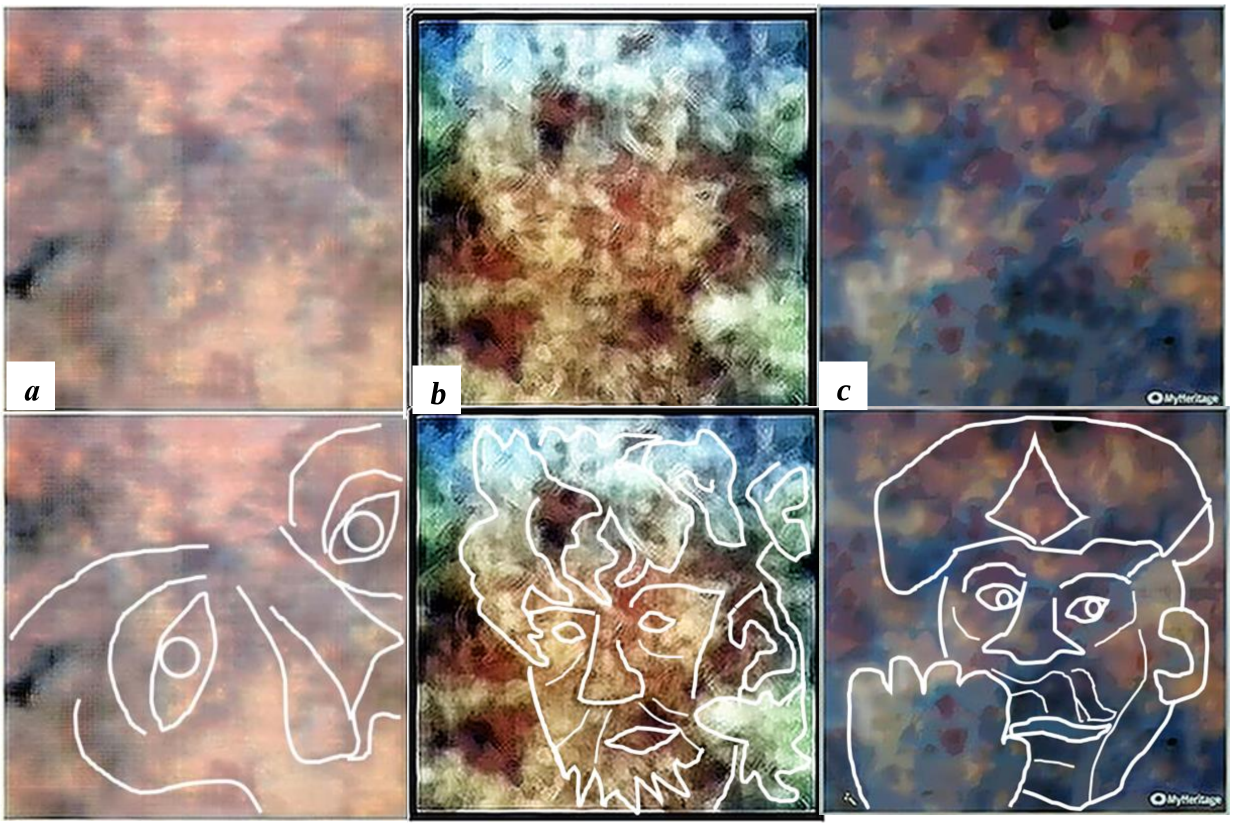

Fig.A8. The image recovered from words containing the neighboring letters of the alphabet from C(c) to E(e) in the position 1 or 2 with pattern rotated 90 degree clockwise **(a)**; from words containing the letters L(l) or M(m) in the position 1,2 or 3 with pattern rotated 90 degree clockwise and color inversion **(b)**; from words containing the letters of the alphabet P(p), Q(q) or R(r) in the position 1,2,3 or 4. The PLS-model (p=0.6, h=1.7, n=10) has been used. Manual fragment markup is at the bottom.

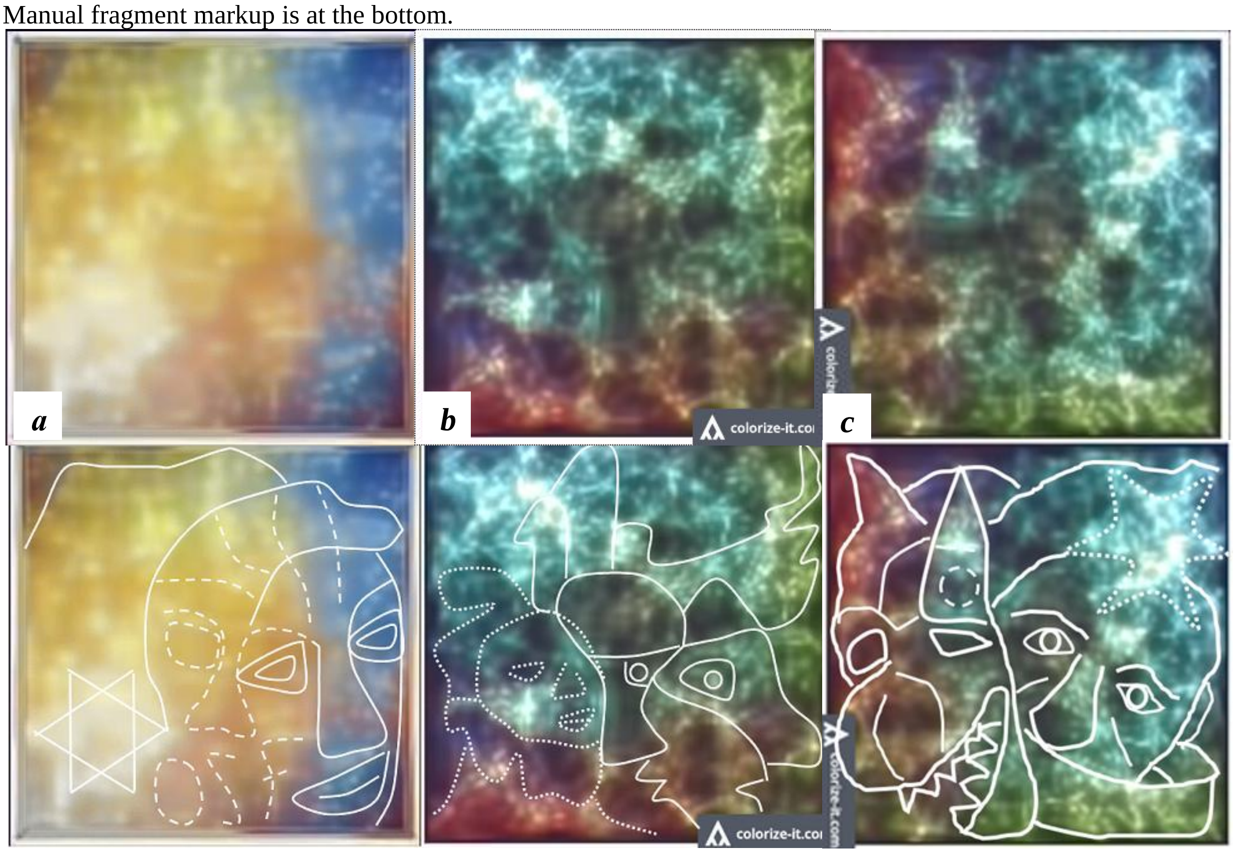

Fig.A9. Images obtained from unique words in quatrains: 760 first unique words from a list sorted alphabetically with pattern rotated 90 degrees contraclockwise, using PLS-model (p=0.6, h=1.7, n=10) ***(a)***; all unique word, using LS-method (d=1, m=1, s_1=s_2=10^{-2}, R_1=20, R_2=10) ***(b)***; the previous image is rotated 90 degree clockwise ***(c)***. Manual fragment markup is at the bottom.

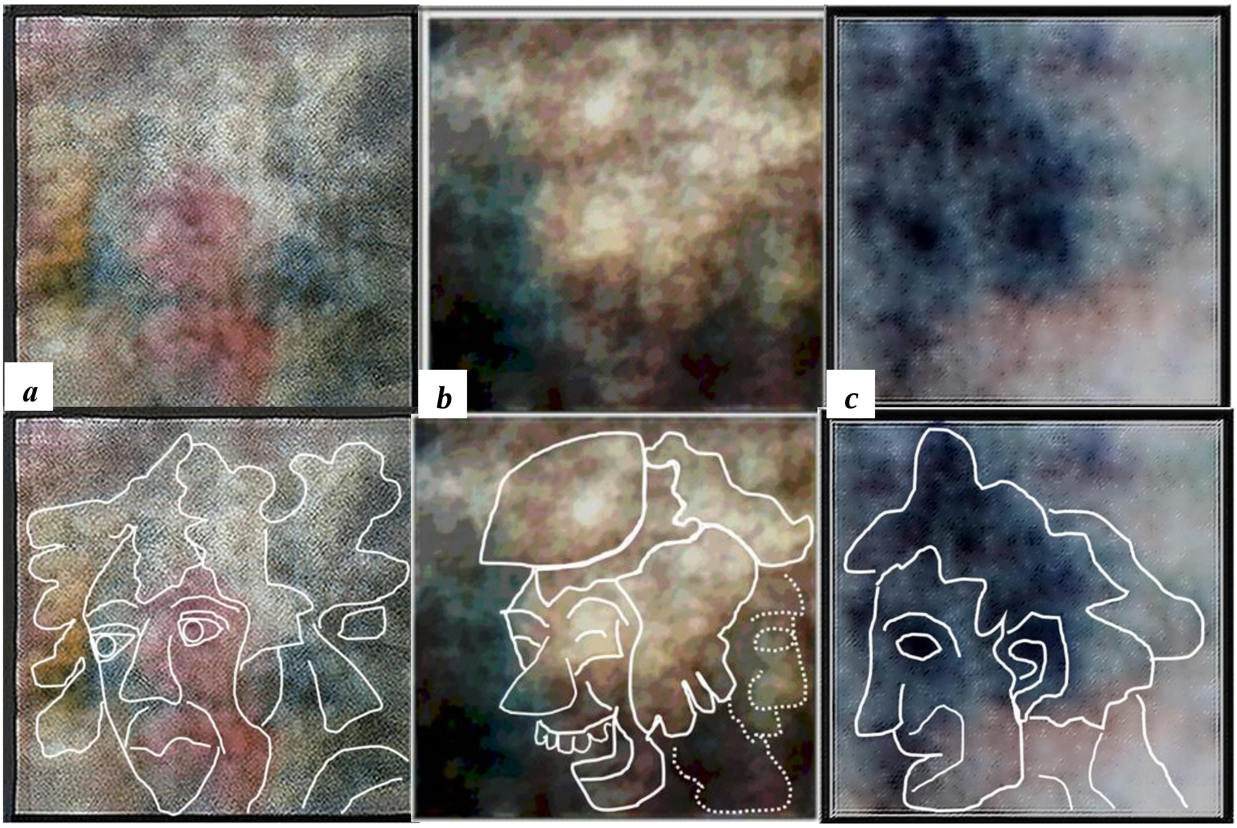

Fig.A10. Images obtained from words beginning with the letters of the alphabet from A(a) to O(o) using PLS-model (*p*=0.5, *h*=1.7, *n*=10) with pattern rotated 90 degrees and brightness inversion **(a)**; from words beginning with all upper and lower case letters present in the name “Nostradamu(v)s” using PLS-model (*p*=1.5, *h*=3, *n*=10) **(b)**; the result of color inversion and rotation 90 degrees contraclockwise of the previous image **(c)**. Manual fragment markup is at the bottom.

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