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EMBEDDING HIDDEN INFORMATION IN IMAGES BASED ON BICUBIC INTERPOLATION

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Abstract. The article is devoted to the study of a well-known steganographic method using an interpolation algorithm. Image magnification algorithms directly affect the quality of image magnification. In this paper, the experiment was carried out on the basis of bicubic interpolation. Bicubic interpolation is most often used in image processing, giving a better picture compared to bilinear interpolation. Many authors have investigated this method, and a good review of existing works was made on our part. We also performed regular — singular value analysis (RS) and obtained the results, the steganographic algorithm is considered resistant to this type of steganalysis. Effective methods of entering hidden information into images using bicubic interpolation type are considered. Experiments were carried out and the results were presented in tabular forms for convenience. The results proved that this method will be used in the future. Also in this article, issues related to the construction of a secret communication channel by embedding hidden messages in digital content (image) were considered, the scope and secrecy of implementation were studied. The experimental results give the user recommendations on how to

use the algorithm to achieve optimal results in accordance with various fields of application. In the future, it is planned to introduce and investigate implementation methods using other interpolation methods.

Keywords: bicubic interpolation, steganography, images, steganalysis, secret message

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БИКУБТЫҚ ИНТЕРПОЛЯЦИЯҒА НЕГІЗІНДЕ СУРЕТТЕРГЕ ЖАСЫРЫН АҚПАРАТТЫ ЕНГІЗУ

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Аннотация. Мақала интерполяция алгоритмін қолдана отырып, белгілі стеганографиялық әдісті зерттеуге арналған. Кескінді үлкейту алгоритмдері кескінді үлкейту сапасына тікелей әсер етеді. Бұл жұмыста эксперимент бикубтық интерполяция негізінде жүргізілді. Бикубтық интерполяция көбінесе кескіндерді өңдеуде қолданылады, бұл екі сызықты интерполяциямен салыстырғанда жақсы кескін береді. Көптеген авторлар бұл әдісті зерттеді және біздің тарапымыздан бар жұмыстарға жақсы шолу жасалды. Біз сондай-ақ тұрақты сингулярлық мәндерді (RS) талдадық және нәтижелерін алдық, стеганографиялық алгоритм стеганализдің осы түріне төзімді болып саналады. Интерполяцияның бикубтық түрін қолдана отырып, суреттерге жасырын ақпаратты енгізудің тиімді әдістері қарастырылды. Эксперименттер жүргізілді және ыңғайлы болу үшін нәтижелер кестелік түрде ұсынылды. Алынған нәтижелер бұл әдістің болашақта қолданылатынын дәлелдеді. Сондай-ақ, бұл мақалада сандық суретке (кескінге) жасырын хабарламаларды енгізу арқылы құпия байланыс арнасын құруға қатысты мәселелер қарастырылды, іске асырудың ауқымы мен құпиялылығы зерттелді. Эксперимент нәтижелері пайдаланушыға әртүрлі қолдану орталарына сәйкес оңтайлы нәтижелерге қол жеткізу үшін алгоритмді қалай пайдалану керектігі туралы ұсыныстар береді.

Болашақта интерполяцияның басқа әдістерін қолдана отырып, іске асыру әдістерін енгізу және зерттеу жоспарлануда.

Түйін сөздер: бикубтық интерполяция, стеганография, суреттер, стеганализ, құпия хабарлама

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ВНЕДРЕНИЕ СКРЫТОЙ ИНФОРМАЦИИ В ИЗОБРАЖЕНИИ НА ОСНОВЕ БИКУБИЧЕСКОЙ ИНТЕРПОЛЯЦИИ

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Аннотация. Статья посвящена исследованию хорошо известного стеганографического метода с использованием алгоритма интерполяции. Алгоритмы увеличения изображения напрямую влияют на качество увеличения изображения. В данной работе эксперимент был проведен на основе бикубической интерполяции. Бикубическая интерполяция чаще всего используется при обработке изображений, давая лучшее изображение по сравнению с билинейной интерполяцией. Многие авторы исследовали этот метод, и с нашей стороны был сделан хороший обзор существующих работ. Мы также выполнили анализ регулярных сингулярных значений (RS) и получили результаты, стеганографический алгоритм считается устойчивым к этому типу стеганализа. Рассмотрены эффективные методы ввода скрытой информации в изображения с использованием бикубического типа интерполяции. Были проведены эксперименты, и результаты для удобства были представлены в табличной форме. Результаты доказали, что этот метод будет использоваться в будущем. Также в этой статье были рассмотрены вопросы, связанные с построением секретного канала связи путем встраивания скрытых сообщений в цифровой контент (изображение), изучены масштабы и секретность реализации. Результаты эксперимента дают пользователю рекомендации о

том, как использовать алгоритм для достижения оптимальных результатов в соответствии с различными областями применения. В будущем планируется внедрить и исследовать методы реализации с использованием других методов интерполяции.

Ключевые слова: бикубическая интерполяция, стеганография, изображения, стеганализ, секретное сообщение

Introduction

There is an enormous amount of media content being transmitted on the Internet. Much of this data is a source of income for its creator and is seen as an object of copyright protection. Given the ease and zero cost of reproduction (creation of a copy) of any file, there is a need to trace its path (from the creator to the end consumer, including the unlicensed one). One of the most effective solutions to this problem is the use of steganography techniques, which use secret messages embedded in the file. Such messages can either identify the author (digital watermarks) or the end user (digital fingerprint) (Daiyrbayeva et al., 2021; Cherikbayeva et al., 2021).

In scientific publications there are works aimed at creating new methods of embedding and at creating new methods of detection (stegoanalysis). The latter are used to detect the facts of information leakage, for example, through official correspondence. Thus, there is an urgent need to analyze existing infiltration methods and create new and effective methods of infiltration of hidden messages (Daiyrbayeva and Yerimbetova, 2021)

Given that the most common type of files transmitted on the Internet are pictures, then the current study focused on the introduction of hidden information in images. Thus, one of the modern approaches of steganography is based on interpolation methods. In particular, the application of interpolation techniques for message embedding, which, in a sense, is a discrete analogue of a hologram, and is commonly used to recover signals and images that have been affected and have resulted in a large loss of information, is investigated (Berikov et al., 2021; Singh et al., 2019).

There are many algorithms for increasing the resolution and scaling of digital images. The simplest methods, called linear ones, perform interpolation using polyphase filtering. This class includes the nearest neighbor method, bilinear and bicubic interpolation, the Lanczos filter, etc (Vaganov et al., 2016)

Popular image zoom methods are methods based on pixel color interpolation. The principle of operation is that for each point of the final image, a fixed set of points of the original image is taken and interpolated in accordance with its mutual position and the selected filter. The number of points also depends on the filter. A degenerate case of interpolation methods is the nearest neighbor method.

If steganography aims at imperceptibly transmitting data embedded in an image so that the fact of embedding itself remains unnoticed, then steganographic analysis (steganalysis) is aimed at detecting embedded data, i.e. the fact of

embedding. Computer steganography involves the introduction of data into almost any container, data loss is possible (bmp, gif, jpeg, etc). In practice, the most common method is the introduction of data into digital images, at the same time, the stegoanalysis of digital images is the simplest and most studied, so all the methods under consideration will be shown by the example of images. Also, a container means an object in which data was embedded to hide. Many methods of steganalysis are based on detecting deviations of the observed multimedia information (stego) from its expected model. The class of statistical methods of steganalysis uses a variety of statistical characteristics, such as: entropy estimation, correlation coefficients, probability of occurrence and dependencies between elements of sequences, conditional distributions, distinguishability of distributions according to the Chi-square criterion, and many others. Simple tests evaluate the correlation dependencies of container elements into which hidden messages can be embedded.

When studying the issues of image steganalysis, a comprehensive analysis of existing works was carried out.

The article (Dryuchenkoe et al., 2022) discusses the problem of digital image steganalysis. The authors presented a new approach based on the use of deep convolutional neural networks with a relatively simple architecture, characterized by the use of additional levels of special processing. Experiments were carried out for several well-known stego algorithms (including the classical block and block-spectral Kutter, Koh–Zhao algorithms, modern EMD, MBEP algorithms and WOW and S-UNIWARD adaptive spatial steganography algorithms) and for stego algorithms based on the use of heteroassociative compression transformations.

The article (Nechta, 2019) discusses the development of a new method for embedding hidden messages in various containers (text, executable files). A new method of steganographic transformation of a binary message is presented, which allows embedding hidden data. It is proposed to convert a message taken from an empty container. The original message is processed as a set of two-bit elements. A sequence of non-repeating elements, called a series, is used to embed a secret message. The embedding was done by rearranging the elements inside the string. The proposed algorithm allows you to simulate the statistical features of a message taken from an empty container, which reduces the likelihood of successful steganalysis. During the experiment, the statistical properties of the message taken from the container before and after embedding were investigated. The analysis was carried out using previously known steganalysis methods based on the detection of statistical differences in messages taken from empty and filled containers. But the use of this algorithm for images is not taken into account.

The article (Agaian et al., 2004) presents a new approach that focuses on the following problems: detection and localization of informative stego areas in digital clean and noisy images; removal of hidden data along with minimizing statistical differences between stego images and a deleted image with stego information. The

new approach presented by the authors is based on a new pixel comparison and a new dimension of complexity. Also, this new measure identifies informative and wall-like areas of the image for the purpose of steganalysis by preserving informative areas and discarding stegoid areas. According to the authors, this method can be used to compress data and conceal classified information in both temporary and transformed areas. It is necessary to pay attention to the fact that it does not depend on the order of color vectors in the palette.

In the work of the authors (Vovk et al., 2015), a proprietary method of embedding information in still images is proposed. The new algorithm used additional cropping and stability blocks during the previous image processing. A comparative analysis of the existing and proposed steganographic system based on quantitative and qualitative characteristics was also carried out. The synthesized method showed excellent results relative to the most common methods and resistance to statistical steganalysis, without detecting significant deviations of the calculated parameters.

The purpose of this work is to investigate the bicubic interpolation method by conducting steganalysis by available means. To conduct the research, we will use RS analysis as the main method of image steganalysis.

Methods and materials

Image scaling is one of the classical problems of computer graphics. A special case of this problem is to reduce and increase the image size by half. These methods play a special role in the compression of raster images, where the overall coding efficiency depends on the quality of approximation.

In this paper, we will investigate a shorthand algorithm for embedding information into digital images using bicubic interpolation.

During the study, an analysis was made of the existing works of authors who are engaged in the study of interpolation, in particular bicubic interpolation:

In the work (Vaganov, Khashin, 2016), a comparative analysis of the quality of some interpolation non-adaptive methods of doubling the image size was carried out. The value of the standard deviation was used as an estimate of the accuracy (quality) of the approximation. The description of interpolation doubling algorithms is given, such as: the nearest neighbor method, linear and cubic interpolation, convolution interpolation with the Lanczos kernel (for a=1, 2, 3), as well as the 17-point interpolation method.

Also in the work (Veselov et al., 2010) the questions of interpolation are investigated. The results obtained in the work will help to create detailed methods for assessing the quality of digital images obtained by modern digital aerial photography systems, as well as to evaluate the technical characteristics of the latter using various types of dashed test polygons.

The article (Trubakov et al., 2017) describes the issues of effective scaling of raster images. The reasons for the appearance of negative effects that occur when increasing the resolution of raster images are considered and analyzed. The efficiency of such methods as the nearest neighbor method, bilinear interpolation

and bicubic interpolation is analyzed. The method of experimental research is considered, the results of comparing algorithms for the quality of the images obtained and the speed are presented. The result of the study is recommendations on the choice of algorithms for increasing the resolution of images.

The paper (Dangwen et al., 2010) discusses the issues of image interpolation. Image interpolation is a method of obtaining a high-resolution image from its low-resolution counterpart, which is often required in many image processing tasks. In this paper, the authors propose edge-oriented bicubic convolution interpolation (BC). The proposed method can adapt well to changing edge structures of images. Experimental results show that this reduces common artifacts such as blurring, blocking and ringing, etc., and significantly exceeds some existing interpolation methods (including BC interpolation) in terms of both subjective and objective indicators.

The authors (Yingmin et al., 2019) in the article considered a bicubic algorithm for image scaling. The bicubic algorithm has the advantages of more accurate image magnification and higher processing speed. Currently, bicubic amplification technology is used in many image processing programs. The authors proposed an improved bicubic interpolation algorithm. Unlike the traditional algorithm, which sets the key parameter a to - 0.5 to guarantee a third-order Taylor approximation, we remove such a requirement, since this value is applicable only to the interpolation of a flat area, while the change in the pixel value of the image is often irregular by direct optimization of the standard deviation of the image, we obtain an optimization function of a higher order. At the same time, a new variable is introduced to replace the a2 term of the optimization function, so that a higher-order optimization problem can be transformed into a least squares problem. Experiments show that optimized parameters have a better reconstruction effect, and obtaining optimized parameters is directly related to image magnification, and the image itself has little effect.

In the article (Watchara Ruangsang et al., 2017), experimental results are verified using processing time and reconstructed images that can be used in real-time applications.

The authors (Shengkui Gao, 2011) present methods of bilinear and bicubic interpolation adapted for the separation of the image polarization sensor in the focal plane. This article discusses five interpolation methods: bilinear, weighted bilinear, bicubic spline, approximated bicubic spline and bicubic interpolation method. The modulation transfer function analysis is applied to various interpolation methods, and test images as well as numerical error analysis are also presented. Based on the comparison results, full-frame bicubic spline interpolation provides the best performance for polarizing images.

The paper (Yongxing Zhang et al., 2022) presents traditional methods of image sampling reduction aimed at removing smoothing artifacts. However, the effect on the quality of an image interpolated from an image with reduced sampling is usually neglected. To solve this problem, the authors propose an interpolation-dependent

downsampling of the image, where interpolation is associated with downsampling. Numerous experimental results demonstrate the viability and effectiveness of the method proposed by the authors.

Basically, any stage of digital image processing has an impact on its quality. Currently, popular methods of image scaling are methods based on pixel color interpolation. The principle of operation is as follows, i.e., for each point of the final image, a fixed set of points of the original image is taken and interpolated in accordance with their mutual position and the selected filter. The number of points also depends on the filter (Sazonov et al., 2013).

The essence of interpolation is to use the available data to obtain the expected values at unknown points. Image interpolation works in two dimensions and tries to achieve the best approximation in pixel color and brightness based on the values of the surrounding pixels (Ki – Hyun Jung, 2009; Bialas-Cie'z and Calvi, 2012).

The simplest type of interpolation method is as follows: *n+1* at the point of the segment *[a,b],* the interpolation node is $x_i (i=0,1,2,...,n)$ and the values of the *f(x)* function are given at these points: $f(x_0) = y_0, f(x_1) = y_1, ..., f(x_n) = y_n$.

Bicubic interpolation is in computational mathematics an extension of cubic interpolation to the case of a function of two variables whose values are given on a two — dimensional regular grid. The surface obtained as a result of bicubic interpolation is a smooth function on the boundaries of neighboring squares, unlike surfaces obtained as a result of bilinear interpolation or nearest neighbor interpolation (Kameneva, 2016).

One of the methods of bicubic interpolation is sequential cubic interpolation, the value of the function f is found by the formula (Eq.1):

$$f(x,y) = [1 y y^2 y^3] A \begin{bmatrix} f(1-,-1) & f(0,-1) & f(1,-1) & f(2,-1) \\ f(0,-1) & f(0,0) & f(1,0) & f(2,0) \\ f(1,-1) & f(0,1) & f(1,1) & f(2,1) \\ f(2,-1) & f(0,2) & f(1,2) & f(2,2) \end{bmatrix} A^T \begin{bmatrix} 1 \\ x \\ x^2 \\ x^3 \end{bmatrix} \quad (1)$$

One of the main methods of statistical steganalysis is the RS method, which was developed by Friedrich et all. in 2001.

The method is based on the analysis of disjoint groups of *n* adjacent pixels, *n* is even (Fridrich, 2001). After selecting the groups, a regularity function is introduced — a function that matches one real number to one group and shows the regularity of the pixels of the group. The value of the regularity function should be the greater the noisier the pixel group is.

As a function of regularity, the sum of the absolute differences (the sum of the differences in values) of the neighboring pixels of the group is selected (Eq.2):

$$f(G) = f(g_1, g_2, ..., g_n) = \sum_{i=1}^{n-1} |g_{i+1} - g_i| \quad (2)$$

Where G is a group of pixels; g_i – is the i^{th} element of the group of pixels *G; n* is the number of pixels in the group.

After calculating the values of the regularity function for all groups of the analyzed image, a group of flip functions («flipping functions») is determined.

The main feature of the RS — method is that it analyzes the quantitative characteristics of small groups of pixels. In this connection, although it is not able to detect the area of potential embedding, it can detect an autopsy performed in random bits, and not sequentially (Vilkhovsky, 2020).

The RS analysis method is used to detect LSB embedding and uses a sensitive method – double statistics obtained from spatial correlations in images (Swain, 2022; Sahu et al., 2019; Daiyrbayeva et al., 2022).

Results

To conduct the experiment, a program was written in the Python environment.

First, a picture is fed to the input, then the bicubic interpolation method was used to enlarge the picture. The following steps describe the use of this method:

Connect the file where this method is written in the form of code.

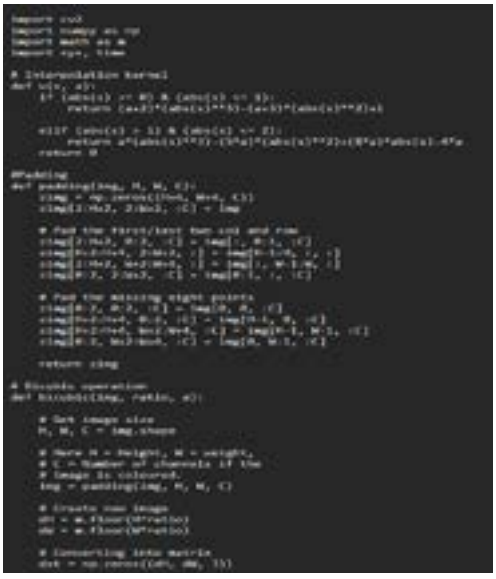

Fig.1 From interpolation, import bicubic

In Fig.1, we take the bicubic method from a file called interpolation, where the logic of enlarging the image is written.

2. We use the cv2 library to read/write the image.

import cv2

3. Create a path string and assign the location of the image there as a string, for example, as *"res_img/interpolated-without-secret/test.png"*.

path = "res_img/interpolated-without-secret/test.png"

4. Create the img variable, where we will store the pixel value as an array using the cv2 library.

img = cv2.imread(path)

in the cv2 library there is an imread method – for reading an image that takes the location of the image. That's where we sell our path.

5. As soon as we read the image and turned the pixel value into an array, we store the response received through the bicubic method in the new variable interpolated.

Interpolated = bicubic (img, a, b)

the bicubic function takes 3 parameters as image, scale and coefficient!

To embed a secret message in our interpolated image, the method «embedding a symbol through the k^{th} step» was used. This is a fairly simple method. The meaning of this method is to select the optimal step for embedding.

Actually, we will describe the steps of encoding and decoding.

Coding Steps:

1. Get the location of the interpolated image, determine which pixel will change (R,G,B).

2. Get the message.

3. Choose step *k*.

4. We run through all the pixels and through the k^{th} step we symbolically change the pixel value to the ASCII character code.

5. As we change the value of the last character to the current pixel, the value of the next pixel will be stop – 0.

6. We return the modified image as an array.

Decoding Steps:

1. Get the location of the interpolated image.

2. Choose step *k*

3. We run through all the pixels and after the kth step we take the pixel value by character, change them from ASCII code to a character.

4. Finish the stop loop – 0.

5. Return the hidden message.

Encoding and decoding is spelled out as a function. Encoding takes three parameters: the location of the image, the message and the step. Decoding takes only two parameters: the location of the image and the step.

The choice of the optimal step depends on you; I would suggest a LCD (the Largest Common Divisor).

To evaluate the steganographic algorithm based on bicubic interpolation, we will use the RS method.

When using the RS method, we introduce the concept of a container. A container is any information intended to hide a message. The choice of the type of container has a significant impact on the reliability of the stegosystem and the possibility of detecting the fact of transmission of a hidden message. When working, a visual container was used. A visual container is a picture or photograph in which small

changes in the brightness of predefined image raster points are used to embed messages.

The empirical capacity of a container is the maximum amount of information that can be written to the container when using the embedding method. The analyzing RS – analysis program outputs the amount of embedded information (L) as a percentage of the empirical capacity of the container, which is calculated as when embedded (Fig. 2).

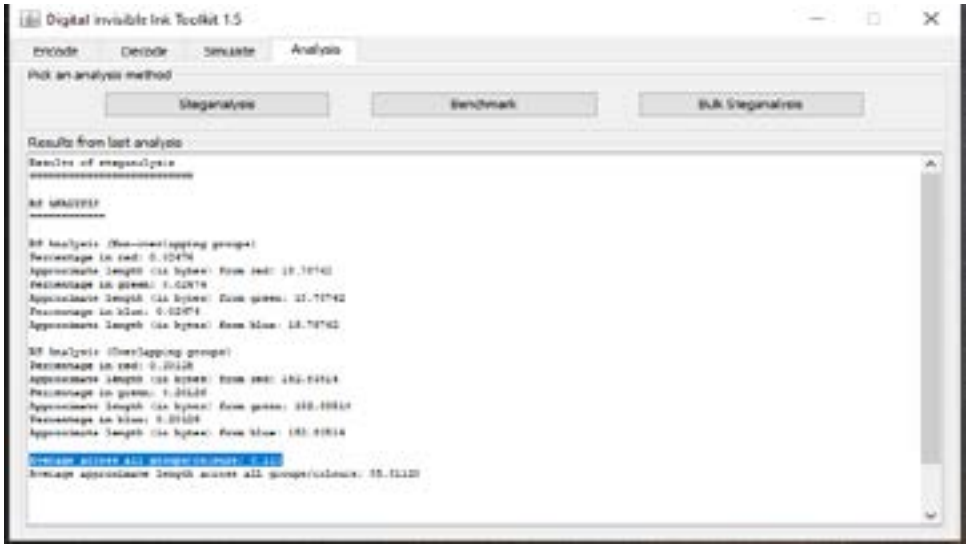

Fig2. RS analysis implementation window

The maximum container capacity in the experiment is 12% and depends on the image.

During the study, 500 (Digital image interpolation, 2021) images of the size 225x225 were used. The results of calculating the type I error are shown in Table 1, where it is shown that the error is 0%. The results of RS analysis are shown in Table 2, according to which it can be seen that the method is relatively resistant to RS analysis.

Table 1 – RS analysis on a set of empty containers (500 images)

L		0%	1-4%	5% or more
File share	225x225	50	49,6	0,4

Table 2 – RS analysis on a set of containers filled using the bicubic interpolation method by 12%

L		0%	1-4%	5% or more
File share	225x225	33,6	64,2	2,2

Obviously, the less information we embed in the image, the less likely it is that detectable features will appear as a result of the implementation process.

Also in the conducted study, we determined the volume of containers filled using the bicubic interpolation method by 12% (Table 3).

Table 3 – Volume of containers filled using the interpolation method by 12%

Archiver	Volume of empty containers	Volume of filled containers
RAR	107MB	141MB
ZIP	187MB	198MB
GZIP	188MB	199MB
BZIP2	156MB	174MB

Discussion

We experimentally implemented bicubic interpolation. A stegoanalysis of this embedding method was carried out, and results were obtained that can be compared with the stegoanalysis of the methods considered in the work (Merzlyakova, 2011).

Based on the results of the study on a set of 500 images of size 225x225, we determined that the percentage of embedding is 12%. The obtained results of calculating the type I error (the case when a filled container is recognized as empty) showed that the error is 0%. The final results of the RS analysis are shown in Table 2, according to which it can be seen that this method is resistant to the RS method and is comparable in durability and capacity with the stegosystem of the permutation method for raster images considered in the work (Merzlyakova, 2011).

Conclusion

The most common interpolation method is bicubic, in which all surrounding pixels are examined for information to create new interpolated pixels. We have implemented and researched a steganographic algorithm based on bicubic interpolation. Based on these principles, a steganalysis of this embedding method was carried out and the results were obtained.

Also, during the study, issues related to the construction of a secret communication channel by embedding hidden messages in digital content (image) were considered, the scope and secrecy of implementation were studied.

In the future, it is planned to implement and investigate implementation methods using other interpolation methods.

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