On Color-to-Gray Transformation for Distributing Color Digital Images

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***Abstract*—A new block embedding algorithm with a secret key is introduced for the Color-to-Gray and Back transformation. Color is embedded into the bit planes of the luminosity component of the YUV color space. We present an interface incorporated into Adobe Photoshop and consider a solution of the high quality digital image distribution problem. The solution is based on idea that the grayscale image with hidden color is a β version of a color original. Then a user could get a gray image before buying its color original he is interested. The proposed protocol has a secret key and can protect original images from unauthorized copying.**

I. Introduction

Being widely spread for digital media protection, the modern steganographic techniques allow to solve several image processing problems, in particular Color-to-Gray and Back transformations. Indeed, in accordance with NTSC (National Television Standard Committee, 1953) recommendation any grayscale image is achieved from color image by a linear combination of red, green and blue color channels. This solution takes into account features of the human vision and gives good results but it is irreversible and the color original can't be retrieved.

A reversible solution has been proposed by Queiroz and Braun [1] and developed by different authors [2], [3], [4]. The idea is to embed color into the grayscale version of a color original and then, for example, after black and white printing to retrieve the color original by extracting the hidden data. Formally this is not a reversible transformation, however steganographic techniques can perform two color images that are indistinguishable visually and this transformation may be considered as reversible.

The Color-to-Gray and Back transformation includes embedding of color data into a grayscale cover image, transformation of the grayscale with hidden data and retrieving of color original. All steps have particular features and were discussed in literature. Considering a set of color models together with embedding algorithms using various orthogonal transformations [5], it has been found that DCT (Discrete Cosine Transform) and YCbCr color space give better performance than DWT (Discrete Wavelet Transform) and RGB first introduced in [1]. Indeed, all color information can't be embedded into grayscale image because a large storage capacity is needed and significant visual changing may be introduced. Then there is a trade-off between the amount of information encoded and the visual quality. The chrominance components are usually subsampled. In the conventional methods it results in noticeable artifacts for the grayscale image with reach texture. The possible solution is adaptive embedding [6].

Main applications of Color-to-Gray and Back transformation discussed in literature include color restoration of printed image, hardcopy data storage and halftone color compression. In the case if a color printer is not available color may be recovered from a printed black and white hardcopy [1], [2]. A Hardcopy Image Backup System [7] has been proposed for archival storage of photos or any analog hardcopies. While a photo is stored the color can be changed or faded and the System creates documents with hidden information about the initial color. In practice the color restoration of printed image is a complicated problem [8], [9]. The reason is that printing and capturing transformation introduce noise that results in degradation of color. Some possible solutions are based on hiding data by halftoning algorithms [10], [11], [12], particular sparse representations [13] and others. Indeed, experimental results indicate that a monochrome camera can be useful to capture printed gray image [14].

The aim of our paper is to implement a Color-to-Gray and Back transformation system suitable for practice. We focus on the color restoration for the digital image distribution problem. The problem is that any user could get the image he is interested before buying and only legitimate user would get the chosen original. It is important because many applications need the high quality photos or color images, particularly images with MOS (Mean Opinion Score) that are often used in image processing. To achieve good quality we use our block embedding algorithm [15], it introduces small changing into grayscale image that results in high PSNR (Peak Signal Noise Ratio). Our algorithm is a basis of the presented interface incorporated with Adobe Photoshop to perform Color-to-Gray transformation.

For protection from unauthorized users the color information may be embedded with a secret key that can be chosen as a set of random positions in which color is encoding [16]. Then only a legitimate user who has the key can recover the accurate color from a transmitted gray image. In this paper we develop idea to allow free access to grayscale image and give color image access only if user has secret key [17]. The free grayscale cover can be considered as a β version of a color image, and we propose a protocol including a secret key to distribute color images among legitimate users. By this way a free access to private databases is limited.

The paper is organized as follows: first we introduce the embedding algorithm, then an experiment and the protocol for image distribution are presented.

II. Color Embedding

The Color-to-Gray and Back transformation is one of the examples that shows how steganographic technique works for image processing applications. We briefly discuss it following Queiroz and Braun.

The solution is based on DWT [1]. A RGB image is transformed into the YCbCr color space, where Y is a luminosity and two chrominance components Cb and Cr keep the color information. One level DWT of luminosity DWT(Y) has four blocks, the size of each block is a quarter of Y. Two blocks are replaced by two quarters of coefficients from Cr and Cr and a new luminosity Y' appears. Then an inverse transform of Y' results in a grayscale version Yc = IDWT(Y') with color embedded. To recover the color we need to reverse the mentioned above steps. According to this approach a quarter of all color information is exploited. That means that the initial and retrieved color images are not equal however they are visually undistinguishable.

All information about color, which is contained in two chrominance components, is impossible to embed into luminosity component, therefore we use the following two features in the scheme. First, resolution of the chrominance components is decreased by means of averaging on neighborhood $a \times a$. In the television standard of data transferring the case $a = 2$ is called 4:1:1. Second, the block embedding algorithm allows to use older bit planes up to $V = 5, 6$ for embedding without appearing visual artifacts. For the transformation between RGB and YUV following equations are used:

$$\begin{vmatrix} Y \\ U \\ V \end{vmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix},$$

$$\begin{vmatrix} R \\ G \\ B \end{vmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y \\ Y \\ V \end{bmatrix}.$$

From a practical point of view the question of dynamic range of the brightness is important. If all pixels values in model RGB belong to the range [0,1], then $Y \in [0, 1]$, $U \in [-0.436, 0.436]$, $V \in [-0.615, 0.615]$. For all chrominance components U and V to belong to the range [0,1], it is needed to make a replacement $U \to (U + 0.436)/0.872$ and $V \to (V + 0.615)/1.23$.

In our model an RGB image is transformed into YUV color space, where Y is a luminosity and $X = U, V$ are two chrominance components. Using a secret key K we create a message

$$M = (K + X)\ mod(255), \tag{1}$$

where K is a random matrix. Note, because of the integer encoding $0, 1, .., 255$ we use modulo 255. Then M is embedded into luminance Y, that is a cover work.

To embed M we use our algorithm [15] that keeps the brightness of an image as far as it is possible. Thus more information can be embedded without introducing noticeable distortions. The algorithm uses the luminosity bit planes and works as follows. Each bit plane Y_V has weight 2^{V-1}, $V = 1, \dots, 8$ and it is divided into a set of non-overlapping blocks $Y_{Va} = \{y[m, n]\}$ of $h \times h$ size. Introduce a parity bit of the block side diagonal

$$d_a = \bigoplus_{x \in Y_{Va}} y[x, h - x].$$

A bit of the message m is encoded by the block Y_{Va} as follows:

$$E :\ Y_{Va} \to S_{Va} = \left\{ \begin{array}{ll} Y_{Va}, & if\ d_a \oplus m = 0, \\ ZY_{Va}, & if\ d_a \oplus m = 1. \end{array} \right\},$$

where the operator Z either modifies a bit of the side diagonal or finds a block S_{Va}, brightness of which is equal or closest to the brightness of Y_{Va}. So brightness of luminance Y is preserved as far as it is possible.

Let's explain the work of the algorithm for the case $h = 2$. In this case bit plane is divided into blocks with size 2×2, using that we can code a bit of message:

$$m \to Z(m),$$

where $m = 0, 1$.

$$Z[m] = \begin{bmatrix} a_m & b_m \\ m \oplus b_m & c_m \end{bmatrix},$$

where $a_m, b_m, c_m = \{0, 1\}$. Since $0 \oplus b_0 = b_0$, the value of the bit $m = 0$ will correspond to the block with zeros or ones on the secondary diagonal. The value of the bit $m = 1$ will be coded by block with zero and one on the secondary diagonal, because $1 \oplus b_1 = 1 - b$. In this case 8 coding blocks will correspond to each value $m = 0$ and $m = 1$

$$0 \to Z[0] = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}, \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}, \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix},$$

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}, \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}, \begin{bmatrix} 0 & 1 \\ 1 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}.$$

If due to the embedding process regular block does not coincide with any one of coding blocks, it is necessary to make transform

$$Z[m] \to Z[1 \oplus m]. \tag{2}$$

It must be done under condition of the equality of brightness, which has a form

$$a_0 + 2b_0 + c_0 = a_1 + 1 + c_1. \tag{3}$$

In the case of transformation $Z[1] \to Z[0]$ condition (3) always holds, because the brightness of the block $Z[1]$ can get four values $1, 2, 3, 4$, for which it is possible to match a_0, b_0, c_0, taking the values 0 or 1. With the transformation $Z[0] \to Z[1]$ we have another situation. The brightness of the block Z[0] can take five values $0, 1, 2, 3, 4$, but for the two of them – 0 and 4, the condition of the equality is not reached, because it is not possible to find the sum of bits $a_1 + 1 + c_1$, which is equal for 0 or 4, and embedding of the bit of the watermark with a value $m = 1$ can be performed to them only by means of changing of the brightness of block.

The following example illustrates how operator Z works in case of $h = 2$.

$$M = \begin{bmatrix} \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{1} \end{bmatrix} \to Y_{Va} = \left[\begin{array}{cc|cc} 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ \hline 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{array}\right];$$

$$S_{Va} = \left[\begin{array}{cc|cc} 0 & \mathbf{1} & 1 & \mathbf{0} \\ \mathbf{0} & 1 & \mathbf{1} & 1 \\ \hline 0 & \mathbf{1} & 1 & \mathbf{1} \\ \mathbf{1} & 0 & \mathbf{0} & 0 \end{array}\right].$$

Here a message M is a 2×2 matrix. Each bit of M is embedded into one of four blocks of Y_{Va}. The stego image S_{Va} consists of four blocks and only one of them, the top right block, has its brightness that is changed to 1.
As result a grayscale image S with encoded color in S_{Va} is achieved. In this case detection algorithm is blind. A hidden message is extracted from the bit plane of the stego image S_{Va} by calculating the parity bit $d_a = m$. Then new chrominance components $X' = U', V'$ are retrieved using the secret key

$$X' = (M - K)\ mod(255).$$

Indeed, a bit plane up to $V = 5, 6$ can be used without introducing any visual changes.

III. Experiment

The work of algorithm, initial RGB image and its luminosity Y of the YUV color space are presented at Fig. 1 and Fig. 2. In our experiment we consider the following questions.

A. Amount of embedded color

Amount of bits H_Y available for embedding depends on number of the bit planes T, the total number pixels n and the size of the block h as $H_Y = nT/h^2$. It is obvious, that all color information can't be hidden into Y. Then we decimate chrominance components U, V by averaging over the $u \times u$ environment. For $u = 4$ amount of color information H_C is $1/8$ from Y or $H_C = (1/8)nk$, where k is a bit depth of the channel Y, U, V. The usual representation has $k = 8$. If $h = 2$ we find $H_Y = (T/4)H_C$. It means that all color information H_C can be embedded if $T = 4$. In another words it needs four bit planes of Y.

B. Degradation due to color embedding

The more information is embedded the more degradation is introduced. Our algorithm keep histogram of grayscale cover Y and a set of bit planes $V = 1, 2, 3, 4$ also $V = 5$ can be used. Fig. 1 presents a distortion measures PSNR.

It describes difference between the cover image Y and the grayscale image S which bit plane V has embedded color. Clear, that the larger V the more distortion is and PSNR decreases. However the PSNR degree is high and even if $V = 4 \div 7$ it takes value $65 \div 47$ dB. This is in accordance

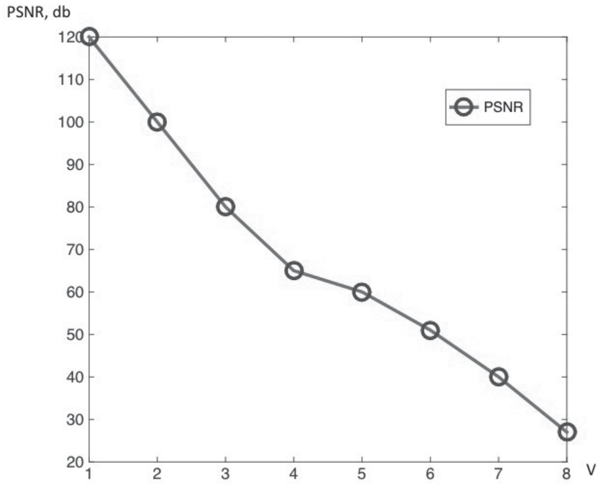

Fig. 1. Distortion measure PSNR vs bit plane V with hidden data

with high visual quality. Really, two images at Fig. 2(b) and Fig. 2(d) are visually indistinguishable in spite of one of them has hidden color in its four bit planes $V = 1, 2, 3, 4$ simultaneously.

Many authors considered PSNR of color images to discuss quality. Unfortunately this measure is not well defined for this case and its simplest generalization given by averaging over the color channels (see, for example, [13]) is not conclusive. Nevertheless in recent work [18] it was reported about PSNR of $20 \div 35$ dB for grayscale image.

C. Color restoration

To achieve the original RGB image, Fig. 2(a), it needs a secret key K. If K is unknown, it can't be found in practice. The reason is that searching of 2^{nk} matrix is a hard problem with the non-polynomial computational complexity. Fig. 2(c) illustrates an example when color is retrieved without the secret key so we take a corrupted key, that has some bits changed. As results a large number of distortions can be found. If the secret key is known the retrieved color image seems to be visually undistinguishable from its original. However there are invisible differences shown at Fig. 3(b) for blue channel.

IV. Interface

For our technique a user interface was designed. The work of the proposed embedding scheme is realized in the full functional information system, which includes client part, integrated into software program Adobe Photoshop (Fig. 4), and server part, containing Web server and application server.

A. Client part

The structure of the proposed module supposes existing of the external interfaces for the reversible transform high level data types to the multidimensional integer-valued arrays and the methods of the watermark extracting. Besides that, the module includes service methods of the reversible transform $RGB \to YUV \to RGB$, function for the calculations hash-sum of the bit array, and also the function of setting safe remote connection using protocol HTTPS based on Synapse library.

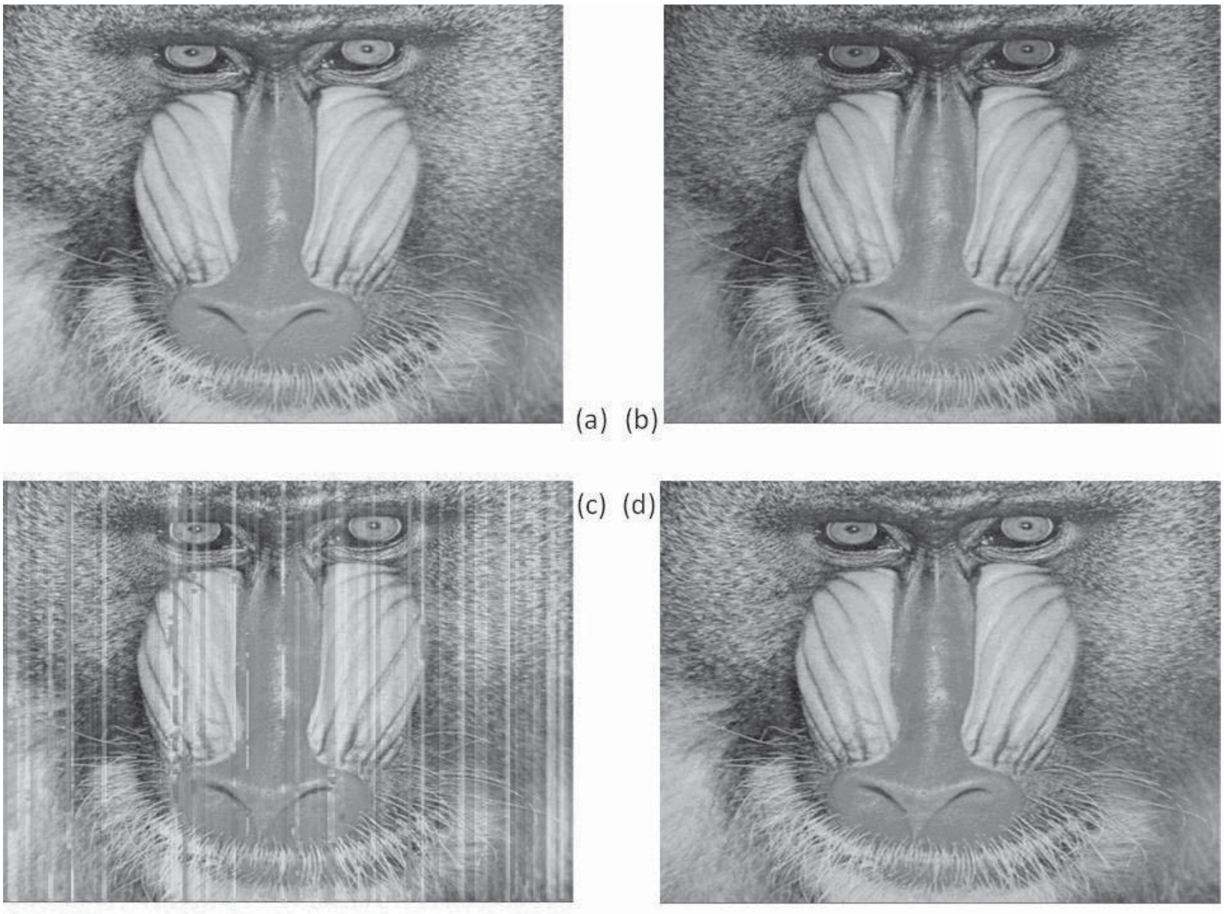

Fig. 2. Color embedding. (a) Color original; (b) cover work image, luminosity component Y of YUV color space; (c) the retrieved original with slightly corrupted secret key; (d) luminosity Y with hidden color

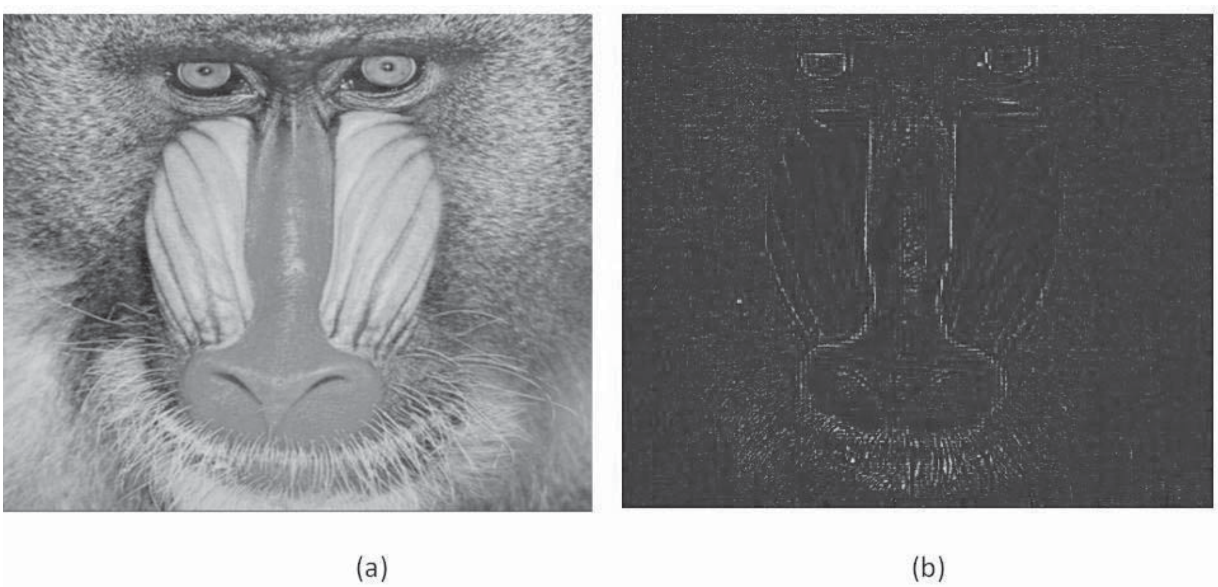

Fig. 3. (a) Retrieved color image; (b) difference in blue channels between the original and the retrieved images

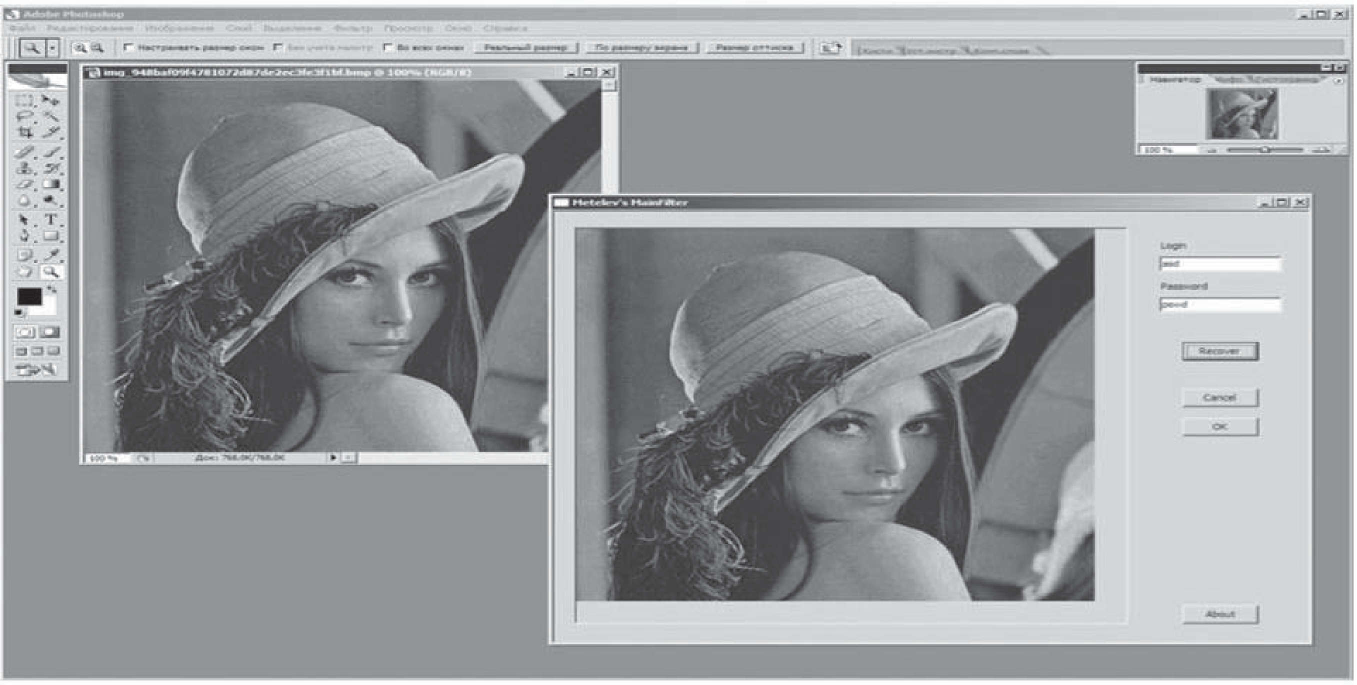

Fig. 4. Adobe Photoshop interface

The scheme of the work of the program is as follows: the user opens preliminary downloaded image in Adobe Photoshop and calls plug-in *Test Watermark* from the pull-down list of the available plug-ins. After opening dialog window, presented at Fig. 4, the user puts his restricted accounts data into corresponding field and presses the button *Recover*.

The program sets protected connection with the server, using the HTTPS protocol, and sends restricted data of the client and hash sum of the processed image. Depending on availability of the Internet connection, accuracy of the entered data, configuration of the remote server and politics of the sale images, different results can be received from the server. In the case of success the program receives specific for this bit array key, using for recovery of the true color image.

B. Server part

The server part performs transformation of original color image into its halftone version with the embedded color and realizes an access to obtained image via Internet. The server can be splitted into three following parts.

1) Coder. It performs automatic processing of the true color image, which was downloaded by author. It is realized basing on the algorithm of the block coding.
2) Web server. It performs two tasks, such as organizing of the access to the halftone pattern via Internet network and providing the protected connection for transfer housekeeping information. Apache server was chosen as a simple configurable tool.
3) Controller. It makes a decision on presenting key to the client and includes data warehouse and logical block.

V. PROTOCOL OF COLOR IMAGES DISTRIBUTING

We introduce our approach with a secret key to the problem of digital images distributing among legitimate users. It may address to high quality photos and database of unique images.

The problem is as follows. *Alice has a digital color image and she wishes to sell it. Bob wishes to by it but before this he wants to get it to know; however Alice distrusts Bob.* The solution can be found using the following protocol. It has next steps.

- Instead of transmitting the original color image A, Alice sends to Bob its grayscale version B with hidden color.
- Bob informs Alice about his decision.
- Alice sends him the secret key and Bob retrieves the desired color image.

As a result Alice keeps her copyright because she uses the secret key and Bob can get the interested image to know it, but this is a grayscale version of original. Another solution can be introduced. Alice has two images, a color original A and its grayscale version B' for free distributing. In this case both images A and B' have to be transmitted through the channel to Bob. Then an adversary Eve can get color image A attacking the channel. It is impossible if Alice uses our protocol because the color image is not transmitted through the channel. As for sending the secret key to Bob, this is a well-known problem of key distribution and Alice can use one of the standard protocols of cryptography.

VI. Conclusions

Steganographic technique is suitable for the Color-to-Gray and Back transformation problem and various solutions can be found. Now an interested user can get a set of algorithms to achieve this transformation and one of the important questions is about possible applications of the developed techniques. Two applications are widely discussed: color restoration of printed images and hardcopy data storage.

In our paper we consider a problem of distribution high quality digital images among legitimate user and introduce a solution based on the Color-to-Gray transformation. This problem is important because of there are a large number of the databases or private collections which images may be interesting for the image processing problems. Indeed, the images with MOS are often used for testing new compression algorithms, distortion measures and other. Some users may wish to get image from database before buying. For this case a solution based on idea of β version can accomplish the request. Considering grayscale image with hidden color as a β version, we propose a protocol for distributing color original.

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