

Pseudo Random Numbers Based Methods for Customized and Secure Image Steganography

Sanjeev Manchanda, Thapar Instt. of Engg. and Tech., Patiala, India; E-mail: smanchanda@tiet.ac.in

Mayank Dave, Thapar Instt. of Engg. and Tech., Kurukshetra, India; E-mail: mdave67@yahoo.com

S. B. Singh, Pnnjabi University, Patiala, India; E-mail: sbsingh69@yahoo.com

ABSTRACT

Steganography is the science of hiding information in media based data. We present random numbers logic based steganographic methods and layout management schemes for hiding data/image into image(s). These methods and schemes can be customized according to the requirements of the users and the characteristics of data/images. These methods are secure enough to meet the requirements of the users and user can play significant role in selection and development of these methods. Methods can be chosen randomly and implemented dynamically based on inputs, user choices as well as outputs. Experimental results are given to demonstrate the performance of the proposed methods.

Keywords: Steganography, Cryptography, Random numbers logic etc.

1. INTRODUCTION

Steganography is the art and science of hiding information in ways that prevent the detection of hidden messages. Steganography, derived from Greek, literally means “Covered writing.” It includes a vast array of secret communications methods that conceal the message’s very existence. These methods include invisible inks, microdots, character arrangement, digital signatures, covert channels, and spread spectrum communications. Steganography and cryptography are cousins in the spy craft family. Cryptography scrambles a message, so that it cannot be understood. Steganography hides the message, so it cannot be seen. A message in cipher text, for instance, might arouse suspicion on the part of the recipient while an “invisible” message created with steganographic methods will not. Modern steganography’s goal is to keep hidden message’s mere presence undetectable, but steganographic systems because of their invasive nature, leave behind detectable traces in the cover medium. Even if secret content is not revealed, the existence of it can be guessed because modifying the cover medium changes its statistical properties, so eavesdroppers can detect the distortions in the resulting stego medium’s statistical properties. The process of finding these distortions is called statistical steganalysis.

In this paper we focus on the developing the techniques that can help hiding messages on the basis of random numbers logic. Present work concentrates upon using Least Significant Bit conversion but is not limited to it. It can involve other methods for steganography discussed in paper. Random numbers based steganographic study is implemented at small scale, but power of random numbers to hide the data/image is not fully exploited and unexplored yet. This paper is an effort to explore the real power of random numbers to hide the messages in secure and customized way.

This paper is organized as follows: Section 2 includes the study of related work. In section 3 we introduce the concept of steganography in more detail, followed by detailed discussion about image processing. In section 4 we discuss about different methods used for steganography. In section 5 includes the proposed methods for steganography based on random numbers logic. In section 6 we discuss few layout management schemes for using methods discussed in section 5. In section 7 we include experimental results to check the strength of proposed methods. Section 8 includes conclusion and future directions for the related research work. Last, but not the least section 9 includes bibliography.

2. RELATED WORK

Steganography is the art of secret communication. Its purpose is to hide the very presence of communication as opposed to cryptography, which aims to make communication unintelligible to those who do not possess the right keys Andersen et al.[1]. The traditional approach to image encoding consists in the source coding, encryption and channel coding Gonzalez et al.[2]. The source coding is used to compress data and match it with the band-width of communication channel. However, the obtained data are sensitive to the communication noise and not protected against unauthorized use. To overcome these disadvantages the next two stages are to be used. To protect data against unauthorized access the encryption is accomplished. The encryption stage is performed separately from source coding. To reduce nuisance of the communication channel noise the channel coding is used which is based on the specialized error correction codes able to detect and correct errors directly during data transmission. Both encryption and channel coding require the introduction of the redundant information in initial data that leads to the increase of data size and corresponded time of transmission. Now a day, we can use digital images, videos, sound files, and other computer files that contain perceptually irrelevant or redundant information as “covers” or carriers to hide secret messages. After embedding a secret message into the cover-image, we obtain a so-called stego-image. It is important that the stego-image does not contain any detectable artifacts due to message embedding. A third party could use such artifacts as an indication that a secret message is present. Once a third party can reliably identify which images contain secret messages, the steganographic tool becomes useless. Obviously, the less information we embed into the cover-image, the smaller the probability of introducing detectable artifacts by the embedding process. Another important factor is the choice of the cover-image. The selection is at the discretion of the person who sends the message. Images with a low number of colors, computer art, images with a unique semantic content, such as fonts, should be avoided as cover images. Some steganographic experts e.g. Aura [3] recommend grayscale images as the best cover images. They recommend uncompressed scans of photographs or images obtained with a digital camera containing a high number of colors and consider them safe for steganography. Pfitzmann and Westfeld [4] introduced a method based on statistical analysis of Pairs of Values (PoVs) that are exchanged during message embedding. Pairs of Values that differ in the LSB only, for example, could form these PoVs. This method provides very reliable results when we know the message placement (such as sequential). However, we can only detect randomly scattered messages with this method when the message length becomes comparable with the number of pixels in the image. Johnson et al. [5, 6] pointed out that steganographic methods for palette images that preprocess the palette before embedding are very vulnerable. Existing cryptographic and steganographic mediums suffer from a myriad of attacks. Johnson [7] has studied such attacks on image steganography while Pal et al. [8] has studied similar attacks in the context of audio steganography. Even though cryptography and steganography are exposed to so many probable attacks, very few people have given a thought to find alternate ways to transmit information. The goal of steganalysis is to defeat steganography methods by identifying the presence of hidden information. This may be done using detection-theoretic methods if the distributions of the cover-image and stego-image are known to the steganalyzer as defined by Cachin [9], and various creative techniques as given by Fridrich et al. [10] etc. Fisk et al. [11] point out the weaknesses of TCP/IP

protocol suite and discuss how those weaknesses could be used as covert channels for secret communication, whereas Bao et al. [12] focus on using communication accessories like email headers etc for secret communication. . Avcibas et al. [13] proposed a steganalysis technique based on image quality metrics. Fard et al. [18] proposed a novel (Genetic Algorithm) GA evolutionary process to make a secure steganographic encoding on JPEG images. Martin et al. [19] experimentally investigated if stego-images, bearing a secret message were statistically “natural”. Koval et al. [20] discussed the problem of performance improvement of non-blind statistical steganalysis of additive steganography in real images. Luo et al. [21] presented a secure LSB steganography system against sample pair analysis, such as RS, SPA and DIH method by adopting chaotic technique and dynamic compensation skill.

3. A CLOSE LOOK OF STEGANOGRAPHY AND IMAGE PROCESSING

3.1 Steganography

There are many forms of steganography including audio, video and image media. These forms of steganography often are used in conjunction with cryptography, so that the information is doubly protected; first it is encrypted and then hidden so that an adversary has to first find the information (an often difficult task in and of itself) and *then* decrypt it. The following formula provides a very generic description of the pieces of the steganographic process:

$$\text{Cover Medium} + \text{Hidden Data} + \text{Stego Key} = \text{Stego Medium}$$

In this context, the *cover medium* is the file in which we will hide the *hidden data*, which may also be encrypted using the *stego key*. The resultant file is the *stego medium* (which will, of course be the same type of file as the cover medium). The cover medium (and thus, the stego medium) are typically image or audio files. In this article, we have focused on image files and therefore, refer to the *cover image* and *stego image*.

3.2 Image Processing

An image file is merely a binary file containing a binary representation of the color or light intensity of each picture element (pixel) comprising the image.

The simplest approach to hiding data within an image file is called *Least Significant Bit (LSB) insertion*. In this method, we can take the binary representation of the hidden data and overwrite the LSB of each byte within the cover image. If we are using 24-bit color, the amount of change will be minimal and indiscernible to the human eye. As an example, suppose that we have three adjacent pixels (nine bytes) with the following RGB encoding:

```
10010101 00001101 11001001
10010110 00001111 11001010
10011111 00010000 11001011
```

Now suppose we want to “hide” the following 9 bits of data (the hidden data is usually compressed prior to being hidden): 101101101. If we overlay these 9 bits over the LSB of the 9 bytes above, we get the following (where bits in **bold** have been changed):

```
10010101 00001100 11001001
10010111 00001110 11001011
10011111 00010000 11001011
```

Note that we have hidden 9 bits successfully, but at a cost of only changing 4, or roughly 50%, of the LSBs.

This description is meant only as a high-level overview. Similar methods can be applied to 8-bit color but the changes, as the reader might imagine, are more dramatic. Gray-scale images, too, are very useful for steganographic purposes. One potential problem with any of these methods is that an adversary who is looking can find them. In addition, there are other methods besides LSB insertion with which to insert hidden information. These methods based on random numbers logic are the subject matter for present paper.

4. IMAGE STEGANOGRAPHY METHODS

Image steganography has been widely studied by researchers. There are a variety of methods used in which information can be hidden in images. Some of them are described here given by Lee et al. [14], Chan et al. [15], Chang et al. [16], and Hsu et al. [17].

4.1 Replacing Least Significant Bit

In image steganography almost all data hiding techniques try to alter insignificant information in the cover image. For instance, a simple scheme proposed by Lee et al. [14], is to place the embedding data at the least significant bit (LSB) of each pixel in the cover image. The altered image is called stego-image. Altering LSB doesn’t change the quality of image to human perception but this scheme is sensitive a variety of image processing attacks like compression, cropping etc.

4.2 Replacing Moderate Significant Bit

Chan et al. [15] showed how to use the moderate significant bits of each pixel in the cover image to embed the secret message. This method improves sensitivity to modification, but it degrades the quality of stego-image.

4.3 Transformation Domain Techniques

Other familiar data hiding techniques use the transformation domain of digital media to hide information discussed by Chang et al. [16] and Hsu et al. [17]. Functions such as the discrete cosine transform (DCT) and the discrete wavelet transform (DWT) are widely applied by Chang et al. [16], and Hsu et al. [17]. These methods hide the messages in the significant areas of the cover image, which makes them robust against compression, cropping and other image processing attacks.

Figure 1. General image steganography system

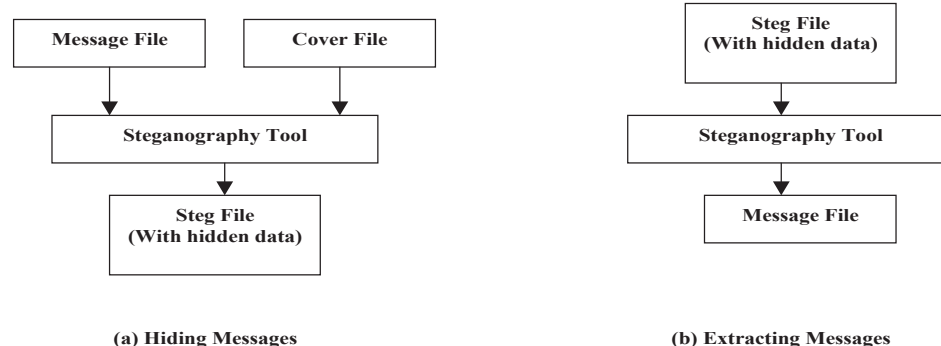
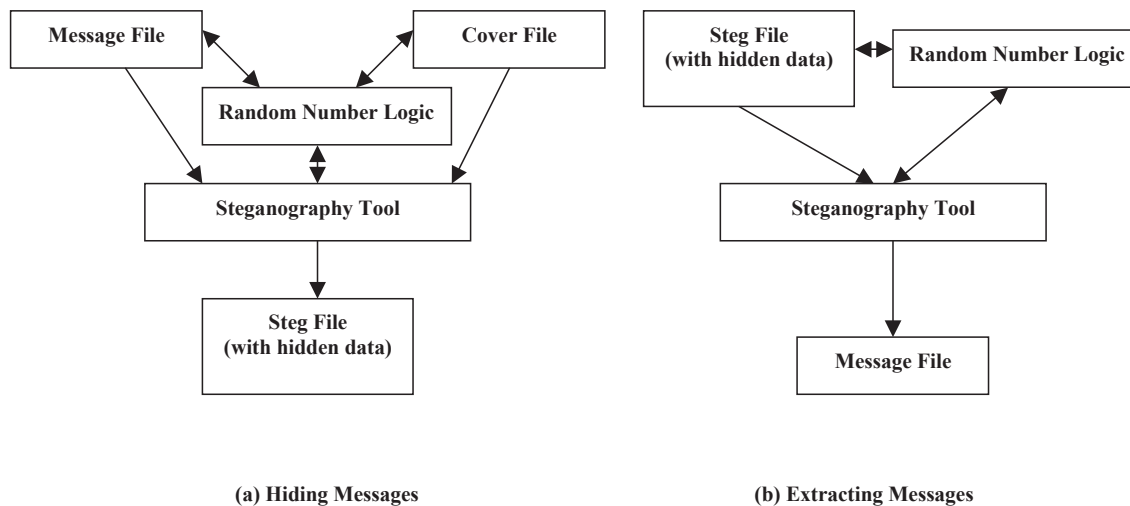


Figure 2. Proposed system based on random number logic



5. PROPOSED METHODS

In proposed system random numbers logic play an important role in Customization and secure implementation of steganography (figure 2). As type of different methods progress more complexity is added to the implementation.

5.1 Type I Methods (Simple Methods)

An obvious method that can be constructed from combination of random numbers generator and least significant bit method (Other methods may also be employed on same tracks, but current paper include only Least Significant Bit based method).

Following general congruential method may be used to generate the location of next bit to be replaced i.e. after x_{i+1} bytes from current byte may be used as target byte to replace the least significant bit.

$$x_{i+1} = f(x_i, x_{i-1}, \dots, x_{i-n+1})(\text{mod } m) = (a_1 x_i + a_2 x_{i-1} + \dots + a_n x_{i-n+1} + \phi) (\text{mod } m)$$

In above Formula all m , n , a , c and x are non-negative integers. Given that the previous random number was x_i , the next random number x_{i+1} can be generated. The numbers generated by a congruential method are between 0 and $m-1$. e.g. suppose that we have three adjacent pixels (nine bytes) with the following RGB encoding:

```
10010101 00001101 11001001
10010110 00001111 11001010
10011111 00010000 11001011
```

Now suppose we want to “hide” the following 4 bits of data (the hidden data is usually compressed prior to being hidden): 1011. Random number generator used for hiding data is

$$x_{i+1} = ax_i + c (\text{mod } m)$$

e. g. $x_0=a=c=7$ and $m=3$ have list of random numbers (called pseudo random numbers) as 2, 0, 1, 2, 0, 1... bits stored for hiding in above data is marked by bold bits in following data, whereas underlined bit represents modified bits.

```
10010101 00001101 11001001
10010110 00001111 11001011
10011111 00010000 11001011
```

The number of successively generated pseudo-random numbers after which the sequence starts repeating itself is called the *period*. Setting up the values of the constants may be divided into two categories of full period or partial period. If the period is equal to m , then the generator is said to have a full period, otherwise partial period. Kelton et al.[22] may be referred for the detailed discussion over setting up the values of these constants. Here we can say that full period methods are observed to be lesser complex and secure as compared to partial period methods.

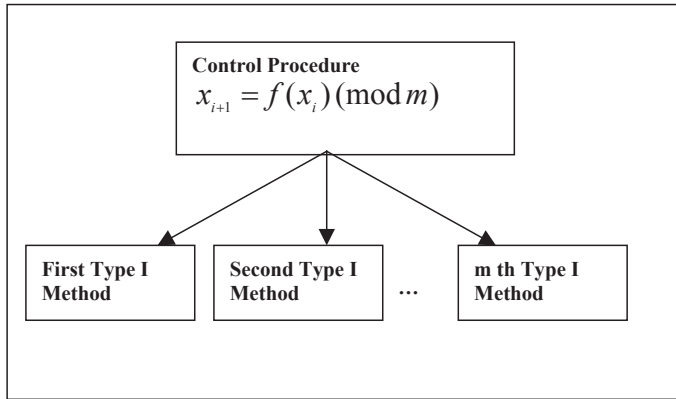
This method will include the hidden data at random places of different byte in the image. This method will inversely affect the density of bits to be stored in cover media by a factor $m/2$ (divisor/2). So there is a need to keep a fit between the divisor m and number of bits in hidden data. Increasing the size of cover media may create suspicion to steganalyst about hidden data in image. So there is a need to check the characteristics of cover image and hidden image to formulate the random number generator variables. Second issue about this method is its security aspect. Different combinations of least significant bits may be analyzed very easily and repetition of same sequence will make the steganalysts' job much easier. So this method is not secure enough to meet the requirement of steganography, this method is very easy and may be customized without much effort. Thousands of combinations of functions and values of variables are available to implement it. So, this method can be customized easily and give initial level of security to data.

5.2 Type II Methods (Low Complexity Methods)

These methods are based on the combinations of two or more type I methods to hide the data. There is a control procedure attached to these methods that controls the sequence of these methods randomly. This randomness is based on the output generated by earlier sequence. Figure 3 will illustrate the procedure of implementing the randomness.

Control procedure decides the method to be used for steganography. The programmer initializes initial values of the variables, whereas later values of variables are generated from the output received from earlier implementation, e.g. Sequence of 100 bytes is used to hide a sequence of 20 bits in it. First 10 bits are stored in first 50 bytes of cover media on the basis of initial values supplied to control procedure. A sequence of methods without repetition is involved for the purpose. Output generated is taken as the source of selecting values for variables. If we need only one value for function f , last few bytes of output may be used for the

Figure 3. Type II low complexity methods



purpose and remaining data is processed on the basis of altered sequence of Type I methods. Implementing the procedure in reverse direction, predefined initial sequence of methods is guided by input data for further iterations, as value of variables is stored in input file. In this way data hiding may be performed in a customized and secure way as functions are decided by users whereas altering sequence of storage can provide security in a well manner.

5.3 Type III Method (Moderately complex methods)

In this type of methods different encryption algorithms are attached to type II methods. Encrypted hidden image is stored in the cover image through type II methods. Key for encryption is generated through random procedures or is decided by the user and prefixed to hidden data/image.

5.4 Type IV Method (Highly Complex Methods)

In this type of methods one set of type III methods is used as one block of stego tool. Two or more such blocks (different from each other) may be combined together in parallel, in series or a combination of both as follows:

5.4.1 Parallel Combination

In this method different block of type II or type III method may be combined together to hide the data. This kind of scheme is suitable for large images. Cover image and hidden image are divided into small parts (blocks) and each block is applied to hide the data. Distribution of data for different blocks is implemented on random numbers logic.

Figure 4. Type III moderate complexity methods

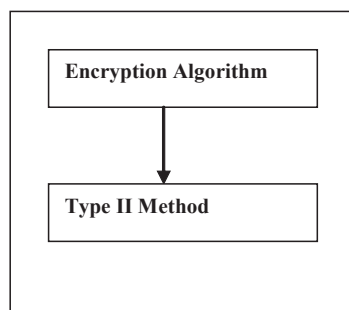


Figure 5. Parallel combination of type III methods

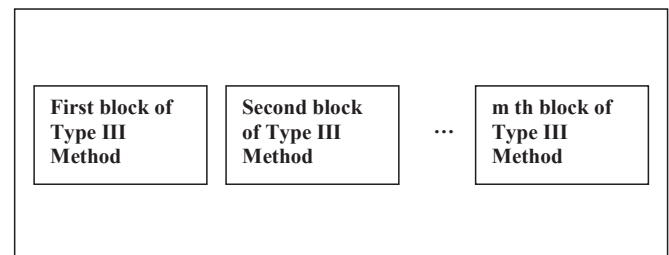
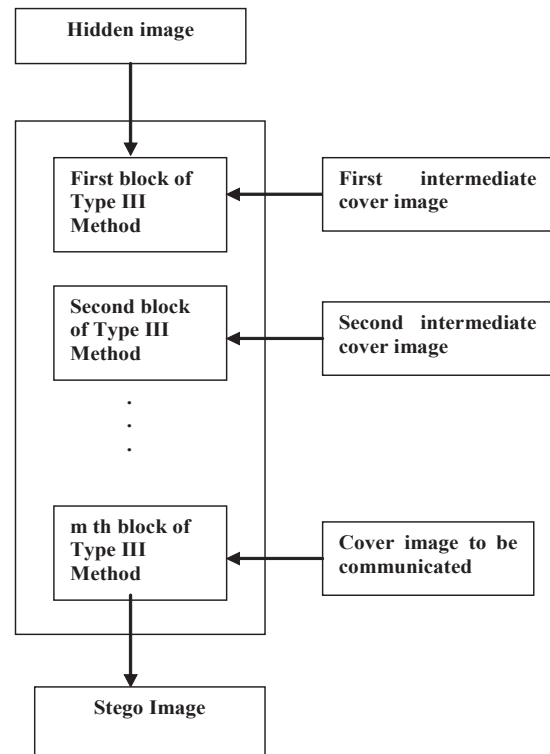


Figure 6. Serial combination of type III methods



5.4.2 Serial Combination

In this method different block of type II or type III method may be combined together to hide the data. This kind of scheme is suitable for relatively small hidden image/data, but security is the major concern. In this method cover image, intermediate cover images and hidden image are used for the purpose as shown in figure 6. Initial hidden image is hidden in intermediate cover image, which is further hidden into cover image and to generate stego image to be communicated. Such a combination is secure enough to be analyzed, but density of data that one can hide will be very less in quantity.

5.4.3 Hybrid Combination

In this method parallel and serial combinations are combined together to hide the data. Different layers of parallel combinations are combined together to hide the data. One parallel combination is called a layer, two or more such layers may be combined together to generate the stego image using intermediate cover images.

Figure 7. Two variations of level 1 schemes



6. LAYOUT MANAGEMENT SCHEMES

Methods discussed in previous section can contribute a lot in hiding information in images. These methods can be made more sophisticated with the help of layout planning. Here layout planning comprises of three basic components i.e. starting point, flow of data and termination point. Starting point is the initial point from where to start hiding information with the help of methods discussed in previous section. Flow of data comprises of the pixel by pixel flow of data hiding in cover image. Termination point is somewhat obvious from the layout i.e. the pixel at which the process of hiding data will terminate. One other component may be the visual sense. By the help of visual senses of eyes, we can decide the part of images, where data can be hidden without being noticed by the stegoanalysis evaluators. Using human eyes may contribute in deciding the part of image, but affects the artificial intelligence of the system, so becomes discretion of user to use it or not. Different Layout Management Schemes are divided under different levels as follows:

6.1 Level 0 (Simple Layout Scheme)

At this level different types of methods are selected from section 5 and are implemented from the starting point of the cover image and continued pixel by pixel from first pixel to last pixel of the image.

6.2 Level 1 (Plain/Garbage Data Insertion)

In this scheme before starting point original(from cover image) plain text or garbage data is placed into cover image followed by the hidden data according to the selection of methods from section 5.

In figure 7 first diagram indicate to leave few pixels before starting and after terminating point, whereas other diagram includes original cover image pixels all around the hidden data. Second diagram is only possible, when hidden data is small as compared to the space available for hidden data in cover image.

6.3 Level 2 (Image Processing Operations Based Scheme)

Before placing hidden data in cover image, cover image pixels may be inverted, rotated or flipped and then hidden data may be placed according to the combinations of methods selected from section 5 and low level layout schemes.

7. EXPERIMENTAL RESULTS

Experiments are performed to check the performance of different methods using variety of random number generators with varying values of variables and constants. Least Significant Bit transformation was the major way to implement the methods but other techniques like moderate significant bit transformation and transformation domain technique were also tried on similar lines, but here we produce the results based on least significant bit transformation based technique. Four hundred such combinations are tried on all four types of methods and results are combined together as follows:

Figure 8. Density chart: Bits hidden per byte vs. value of divisor

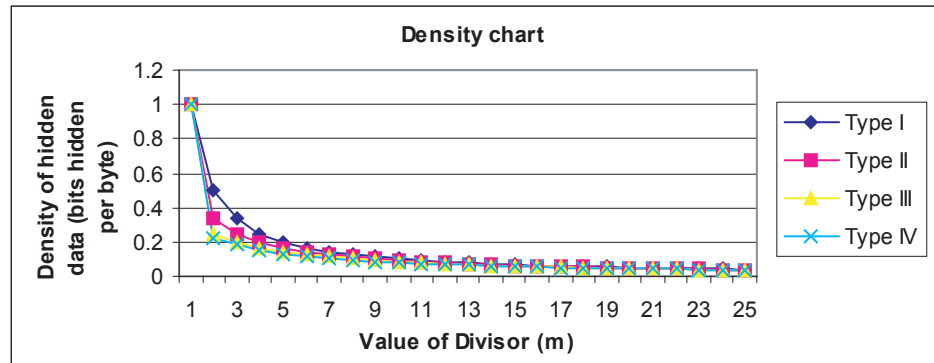
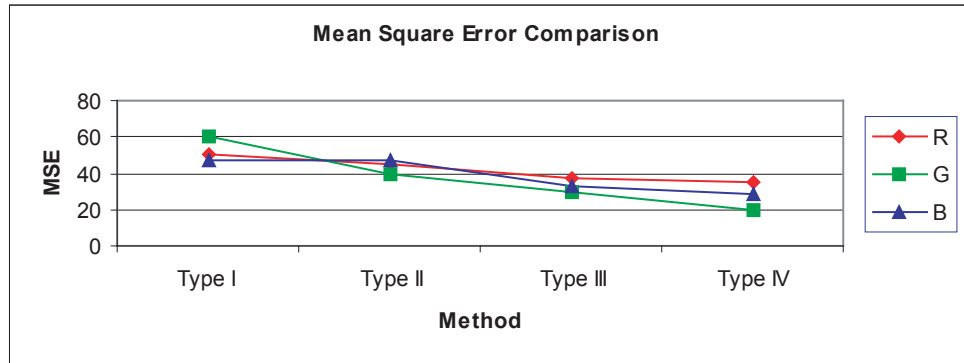


Figure 9. Mean square error comparison: Mean square error vs. Type(s) of method.



7.1 Density of Hidden Data

First of all one of the most important issue is that how much data can be stored in cover image and selection of suitable divisor. A simple Least Significant Bit method requires n bytes for hiding n bits. This density is decreased m times of total storage capacity for type I method and it is further degraded for other methods as shown in the figure.

It is obvious to receive more densely placed hidden data for smaller value of divisor 'm' as compared to a larger one and it is being indicated in figure 8 as well.

7.2 Quality of Cover image

There are many metrics to quantify the quality of two or more images. To compare these methods objectively, we adopt Mean Square Error (MSE) as our quality metrics. The MSE between the original image $I_o(x,y)$ and the stego image $I_r(x,y)$ for each color channel is defined as :

$$MSE = \frac{\sum_{x=1}^m \sum_{y=1}^n [I_o(x,y) - I_r(x,y)]^2}{m \cdot n}$$

where $m \times n$ is the size of the image

Results indicate that type I methods hides more data so these affect the color combination of different image it, but less for other methods.

7.3 Security of Hidden Image

Different tools available in market like s-tools, EzStego, Stegdetect, Stego suite etc. are tried on different methods and it is being observed that these tools are well conversant with type I methods, but are unable to detect the presence of hidden data of other complex combinations.

Experiments performed on all four types of methods through different tools available for steganalysis indicate that complex combination of methods are very secure as compared to the simpler one and figure 10 confirms it as well.

7.4 Complexity of Algorithms for Different Methods

Numbers of lines used executed for hiding data increases rapidly as we use more complex methods. As type I is simple method, it is less complex. Complexity increases as we use further much more complex methods.

Figure 11 indicates that complexity of algorithms increases as we move from simple to complex methods. Following images are included to show that image 'a' and 'c' can't be distinguished by human eyes, but these are significantly different from each other.

8. CONCLUSION AND FUTURE DIRECTIONS

In current paper we have applied random numbers based methods on least significant bit transformation for steganography. We formulated thousands of variants based on users' choices and calculated the results of around four hundred such combinations. Results cover the security, complexity, density and quality aspects of these methods. Authors are working upon more complex layout management schemes in a combination with these methods. In future, research work will be continued on

Figure 10. Security chart: Security probability of different methods

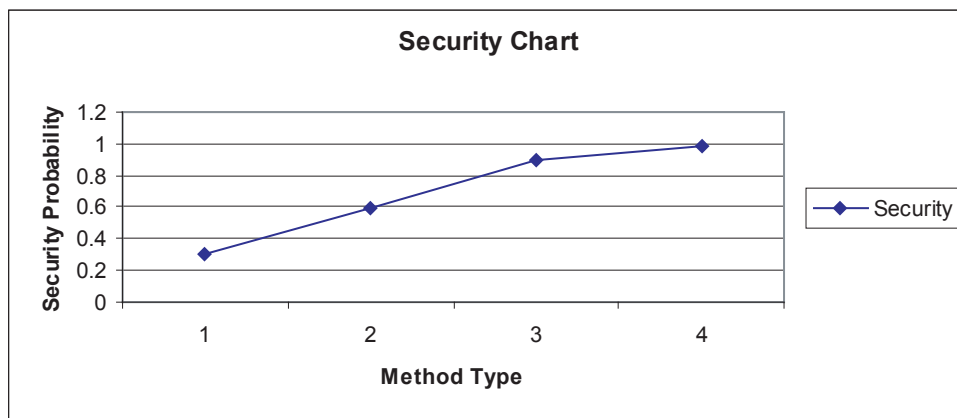


Figure 11. Complexity chart: Lines of code executed for hiding numbers of bits in cover image

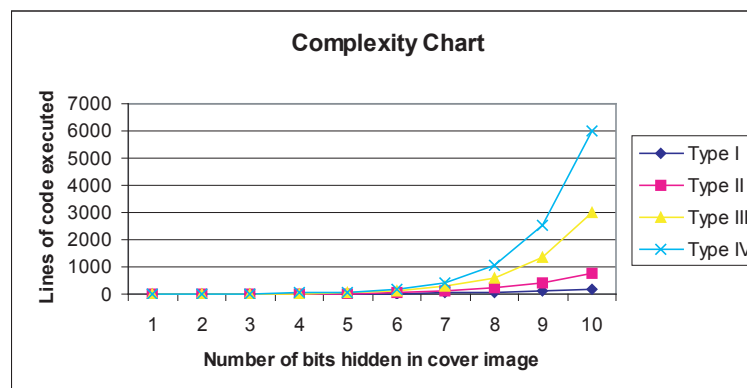
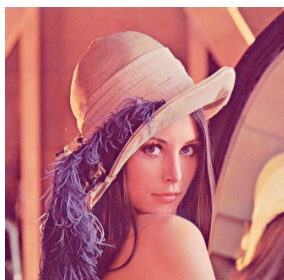
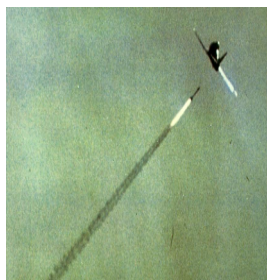


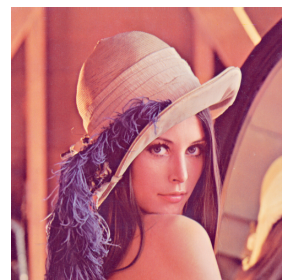
Figure 12. Steganography images: Differentiating images 'a' and 'c' is impossible through eyes.



(a) Cover image (Lena.tiff)



(b) Hidden image (missile.bmp)



(c) Stego image (lenaNew.tiff)

similar lines for implementing more such combinations as well as layout management schemes and for creating steganalysis tools for such combination.

9. REFERENCES

- [1] Andersen, R.J. and Petitcolas, F.A.P., "On the limits of steganography," *IEEE Journal of Selected Areas in Communications, Special Issue on Copyright and Privacy Protection* 16 No.4 (1998) 474-481.
- [2] Gonzalez R.C. and Woods R.E.: Digital Image Processing. Addison Wesley, Reading, 1992.
- [3] Aura T., "Practical invisibility in digital communication," Lecture Notes in Computer Science, vol.1174, Springer-Verlag, 1996, pp. 265-278.
- [4] Westfeld A. and Pfitzmann A., "Attacks on Steganographic Systems," Lecture Notes in Computer Science, vol. 1768, Springer-Verlag, Berlin, 2000, pp. 61-75.
- [5] Johnson N. F. and Jajodia S., "Steganography: Seeing the Unseen," *IEEE Computer*, February 1998, pp.26-34.
- [6] Johnson N. F. and Jajodia S., "Steganalysis of Images Created Using Current Steganography Software," Lecture Notes in Computer Science, vol.1525, Springer-Verlag, Berlin, 1998, pp. 273-289.
- [7] Johnson, N. F., "Steganalysis of images created using current steganographic software", in *Second Information Hiding Workshop*, 1998.
- [8] Pal S.K., Saxena P. K., Mutto S.K., "The Future of Audio Steganography", in *Pacific Rim Workshop on Digital Steganography*, Japan, 2002.
- [9] Cachin C., An information-theoretic model for steganography, in D. Aucsmith (Ed.): *Information Hiding, 2nd International Workshop*, vol. 1525 of *Lectures Notes in Computer Science*, pp. 306-318. Springer, 1998.
- [10] Fridrich J. and Goljan M., Practical steganalysis of digital images-state of the art, *Proc. SPIE PhotonicsWest, Vol. 4675*, pp. 1-13, San Jose, California, Jan. 2002.
- [11] Fisk G., Fisk M., Papadopoulos C., Joshua N., "Eliminating Steganography in Internet Traffic with Active Wardens", Available: [http://citeseer.nj.nec.com/fisk02eliminating.html] Nov 1, 2002.
- [12] Bao F., Wang X., "Steganography of short messages through accessories", in *Pacific Rim Workshop on Digital Steganography*, Japan, 2002.
- [13] Avcibas I., Memon N., and Sankur B., "Steganalysis using image quality metrics," *IEEE Transactions on Image Processing*, vol. 12, pp. 221-229, Feb. 2003.
- [14] Lee, Y. K., Chen, L. H., (2000), "High Capacity Image Steganographic Model", in *IEE Proceedings Vision, Image and Signal Processing*, pp. 288-294.
- [15] Chan, Y. K., Chang, C. C., (2001), "Concealing a Secret Image Using the Breadth First Traversal Linear Quad tree Structure", in *IEEE Proceedings of Third International Symposium on Cooperative Database Systems for Advanced Applications*, pp. 194-199.
- [16] Chang, C. C., Chen, T. S., Chung, L. Z., (2002), "A Steganographic Method Based upon JPEG and Quantization Table Modification", *Information Sciences*, vol. 141, pp. 123-138.
- [17] Hsu, C. T., Wu, J. L., (1999), "Hidden Digital Watermarks in Images", in *IEEE Transactions on Image Processing*, pp. 58-68.
- [18] Fard Amin Milani, R. Mohammad, T. Akbarzadeh and A. Farshad Varasteh, "A New Genetic Algorithm Approach for Secure JPEG Steganography",
- [19] Martín Alvaro, Sapiro Guillermo and Seroussi Gadiel, "Is Image Steganography Natural?", *IEEE TRANSACTIONS ON IMAGE PROCESSING*, VOL. 14, NO. 12, DECEMBER 2005
- [20] Koval Oleksiy, Voloshynovskiy Svyatoslav, Holotyak Taras and Pun Thierry, "Information-theoretic Analysis of Steganalysis in Real Images"
- [21] Luo Xiangyang, Hu Zongyun, Yang Can, Gao Shanqing, "A Secure LSB Steganography System Defeating Sample Pair Analysis Based on Chaos System and Dynamic Compensation", Feb. 20-22, 2006 ICACT 2006.
- [22] Kelton W. D. and Law A., Simulation Modeling and Analysis, McGraw-Hill Science, USA.

0 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage: www.igi-global.com/proceeding-paper/pseudo-random-numbers-based-methods/33431

Related Content

A Comparative Study of Infomax, Extended Infomax and Multi-User Kurtosis Algorithms for Blind Source Separation

Monorama Swaim, Rutuparna Panda and Prithviraj Kabisatpathy (2019). *International Journal of Rough Sets and Data Analysis* (pp. 1-17).

www.irma-international.org/article/a-comparative-study-of-infomax-extended-infomax-and-multi-user-kurtosis-algorithms-for-blind-source-separation/219807

Social Welfare-Based Task Assignment in Mobile Crowdsensing

Zheng Kang and Hui Liu (2023). *International Journal of Information Technologies and Systems Approach* (pp. 1-28).

www.irma-international.org/article/social-welfare-based-task-assignment-in-mobile-crowdsensing/326134

Interpretable Image Recognition Models for Big Data With Prototypes and Uncertainty

Jingqi Wang (2023). *International Journal of Information Technologies and Systems Approach* (pp. 1-15).

www.irma-international.org/article/interpretable-image-recognition-models-for-big-data-with-prototypes-and-uncertainty/318122

Computational Biology

Michelle LaBrunda, Mary Jane Miller and Andrew La Brunda (2015). *Encyclopedia of Information Science and Technology, Third Edition* (pp. 448-457).

www.irma-international.org/chapter/computational-biology/112356

Privacy, Algorithmic Discrimination, and the Internet of Things

Jenifer Sunrise Winter (2018). *Encyclopedia of Information Science and Technology, Fourth Edition* (pp. 4951-4961).

www.irma-international.org/chapter/privacy-algorithmic-discrimination-and-the-internet-of-things/184198