JPEG Steganography System with Minimal Changes to the Quantized DCT Coefficients

Hamdy A. Morsy, Zaki B. Nossair, Alaa M. Hamdy, Fathy Z. Amer

Abstract—Steganography is the science of invisible communications over an innocuous cover medium. Most steganographic systems defeat both visual and first order statistical attacks however they offer only low capacity embedding. In this paper, a new steganographic system is introduced for message embedding by inverting the LSB of DCT coefficients of JPEG image. This algorithm offers high capacity compared to existing steganographic system.

Index terms—JPEG hiding, steganography, steganalysis, information hiding.

I. INTRODUCTION

Steganography is the art and science of hiding communications between two parties over an innocuous cover medium, so that it can not be suspected by an eavesdropper. In contrast to encryption where the goal is to secure communications from an eavesdropper, steganographic techniques strive to hide the very presence of the message itself from an attacker.

Steganography refers to the hiding of information in a medium (such as image, audio, or video). Any medium with redundant bits that is used for embedding data is called a cover medium. After embedding message bits in a cover medium, a stego medium is obtained [1, 2]. The embedding technique is assumed to be known to the public according to Kerckhoffs principle [3, 4]. Therefore the embedding process may use an embedding key (stego key) so that only the intended user can successfully extract the embedded data by using the extraction key in the extraction process.

The general idea of hiding some information in digital media has a wider class of applications that go beyond steganography, Fig. 1. The techniques involved in such applications are collectively referred to as information hiding. Information can be gathered about an image from its electronic form or its printed form. For example, an image printed on a document could be annotated by metadata that could lead a user to its high resolution version. In general, metadata provides additional information about an image [5].

Digital watermarking is considered to be a type of information hiding and is defined as the process of embedding information into digital multimedia contents such that the information (the watermark) can later be extracted or detected for a variety of purposes including copy prevention and control. Digital watermarking has become an active and important area of research, and development and commercialization of watermarking techniques is being deemed essential to help address some of the challenges faced by the rapid proliferation of digital content. The key difference between information hiding and watermarking is the absence of an active adversary. In watermarking applications like copyright protection and authentication, there is an active adversary that would attempt to remove, invalidate or forge watermarks. In information hiding there is no such active adversary as there is no value associated with the act of removing the information hidden in the content. Nevertheless, information hiding techniques need to be robust against accidental distortions.

In general, a steganographic system starts by identifying redundant bits in a cover medium. Redundant bits are those bits that can be modified without distorting the statistical properties of the cover medium. A steganographic system exploits these redundant bits for message embedding without changing the statistical properties of the cover medium. In most steganographic systems, modifying the redundant bits leaves detectable traces. Even if the hidden message is not exposed, the existence of it is detected.

The communication, in a steganographic system, is taken place in such a way that an attacker can not suspect that there is a hidden message is exchanged between two parties other than exchange of media files. A powerful steganographic technique exploits only the redundant bits to embed message bits without distorting the cover media statistical properties.

After embedding the message bits in an innocuous cover medium, the resulting stego medium should be secure against visual and statistical attacks and robust against modification such as recompression. Most steganographic systems are weak against visual and statistical attacks and the ones that are robust against these visual and statistical attacks offer only relatively small capacity [6, 7].

Although modifying the redundant bits doesn't affect significantly the statistical properties of the cover medium. Distortions to the histogram of the transform domain can be observed after embedding message bits. As a result, an eavesdropper can detect the distortion in the resulting stego medium's statistical properties. Statistical steganalysis is the science that concerned with finding distortions in the cover medium and hence labels the cover medium if it has a hidden message.

Manuscript received November, 3, 2011.

H. A. Morsy, is with the Telecommunication Department, Helwan University, Cairo 11792, Egypt (e-mail: hmorsy@helwan.edu.eg).

Z. B. Nossair, is with the Telecommunication Department, Helwan University, Cairo 11792, Egypt (e-mail: znossair@helwan.edu.eg).

A. M. Hamdy, is with the Telecommunication Department, Helwan University, Cairo 11792, Egypt (e-mail: ahamdy@helwan.edu.eg).

F. Z. Amer, is with the Telecommunication Department, Helwan University, Cairo 11792, Egypt (e-mail: famer@hlewan.edu.eg).

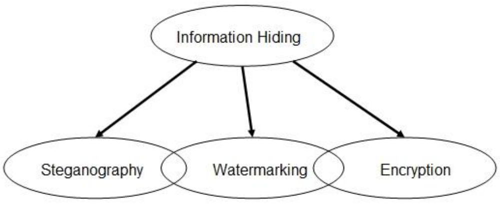


Fig. 1 Steganography and related fields

Internet users transmit digital pictures over email and other Internet communication. JPEG is one of the most common formats for images. As a result, this format is the best candidate for using as a cover medium for exchanging secret messages without raising an eavesdropper's suspension. The Least-significant bits (LSB) of nonzero of discrete cosine transform (DCT) coefficients are modified for message embedding.

In this paper, a new technique, the Inverted Steganographic Algorithm (ISA), is introduced for message embedding in the LSB of nonzero AC DCT of JPEG images. This steganographic system is based on inverting each LSB bit flipped by message bit with the corresponding bit in the pair of values (PoVs) of the DCT coefficients. The nonzero AC DCT coefficients are divided into pairs of values , for example (1,2), (-1,-2)… etc, if the selected bit is different from the data bit, the LSB bit will be inverted and the first next LSB bit in the same PoVs will be inverted too . As a result, the total changes due message embedding will be zero given that the maximum message embedding limited to the lower number of bits in each PoVs. More data bits can be embedded with preserving the statistical properties of the cover medium. This algorithm provides maximum capacity compared to the state of the art steganographic algorithms. The performance will be studied on both spatial domain and transform domain.

The rest of this paper is organized as follows. In section II, JPEG image format is introduced. ISA algorithm is presented in section III. Comparisons between the proposed algorithm and the current steganographic algorithms and simulation results are presented in section IV. Conclusions are presented in section V.

II. JPEG IMAGES

A. Steganography

In JPEG image formats, Joint Photographic Expert Group, each 8 x 8 block of pixels of the image are transformed into 64 DCT coefficients. The DCT coefficients $F(u, v)$ of an 8 x 8 block of image pixels $f(x, y)$ are given by:

$$F(u,v)=\frac{1}{4}C(u)C(v)\left[\sum_{x=0}^{7}\sum_{y=0}^{7} f(x,y)*\cos\frac{(2x+1)u\pi}{16}\cos\frac{(2y+1)v\pi}{16};\right] \quad (1)$$

Where

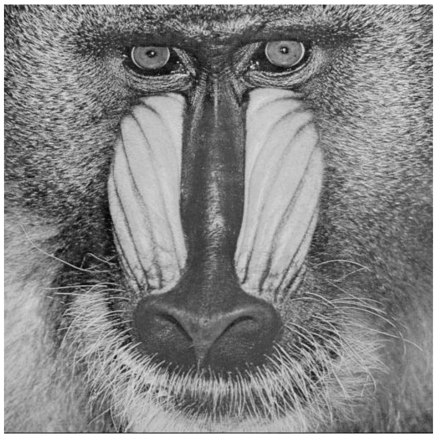
$$C(x)=\begin{cases}\frac{1}{\sqrt{2}} & \text{x}=0\\ 1 & \text{otherwise}\end{cases}$$

Afterwards, the following operation quantizes the coefficients:

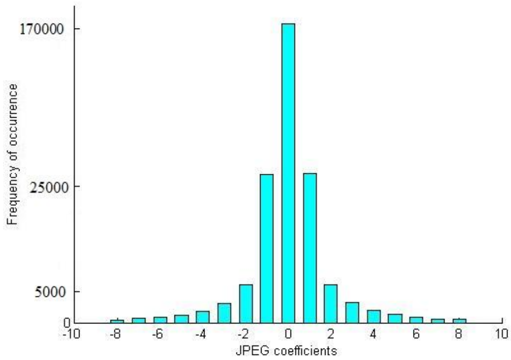
$$F^{Q}(u,v)=\left\lfloor\frac{F(u,v)}{Q(u,v)}\right\rfloor, \quad (2)$$

Where $Q(u, v)$ is a 64-element quantization table.

We can use the least-significant bits of the quantized DCT coefficients as redundant bits in which the secret message can be embedded. The modification of a single DCT coefficient affects all 64 image pixels [8]. Fig. 2 shows an image (standard Baboo test image 512x512) with its frequency of occurrences of DCT coefficients.



(a)



(b)

Fig. 2. Standard test image and its histogram: (a) Bridge, (b) The histogram

The DCT coefficients are divided into pairs of values (PoVs), for example (1, 2), (-1, -2), (3, 4)... etc. Fig. 2 shows the histogram of frequency of occurrences of DCT coefficients, one can notice that the odd DCT coefficients occur more frequently than the adjacent even DCT coefficients. As an assumption, the message bits are uniformly distributed. As a result, embedding this type of message can significantly distort the first order statistical properties of the JPEG image.

The Jsteg algorithm, by Derek Upham, was the first publicly available steganographic system for JPEG images. Its embedding technique sequentially replaces the least-significant bit of DCT coefficients with the message's data. This algorithm excludes the DC DCT coefficients and the values zeros and ones of AC DCT coefficients. With uniformly distributed message bits, every pair of values will be equalized after embedding [11, 12, 13].

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

B. Steganalysis

Assume k is the distinct AC DCT coefficients of a JPEG image and c is the nonzero AC DCT coefficient index of DCT transform and the frequency of occurrence of two adjacent DCT coefficients are n_i and n_{i+1}. One can observe that the absolute value of frequency of occurrences of the histogram is monotonically decreasing as shown in Fig. 2, which means that $n_i > n_{i+1}$. For a uniform distributed message, the number of frequency of occurrences of the LSB of nonzero AC DCT coefficients n^*_i and n^*_{i+1} will be equal due to message embedding. The following relation can be hold:

$$|n_i - n_{i+1}| \geq |n_i^* - n_{i+1}^*|. \tag{3}$$

Based on this observation, Westfeld and Pfitzmann designed a first order statistical test to detect the similarity of the PoVs of stego images [9, 10]. This statistical steganalysis is known as Chi-square attack.

The average number of each pair of values is given by:

$$n_i^* = \frac{(n_i + n_{i+1})}{2} \tag{4}$$

And the Chi-square test can be calculated as:

$$x^2 = \sum_{i=1}^{k} \frac{(n_i - n_i^*)^2}{n_i^*} \tag{5}$$

The probability of embedding as a function of Chi-square value is given as:

$$p = 1 - \frac{1}{2^{\frac{k-1}{2}} \Gamma(\frac{k-1}{2})} \int_0^{x^2} e^{-\frac{t}{2}} t^{\frac{k-1}{2}-1} dt \tag{6}$$

Where *k* is the degree of freedom – 1, the distribution of DCT coefficients of a JPEG image can be tested for uniform distribution using equation (5). Fig. 3 shows the histogram of stego image with 100 % embedding rate using Jsteg algorithm. It is clear that, every pair of values are equal due to embedding message of uniform distribution.

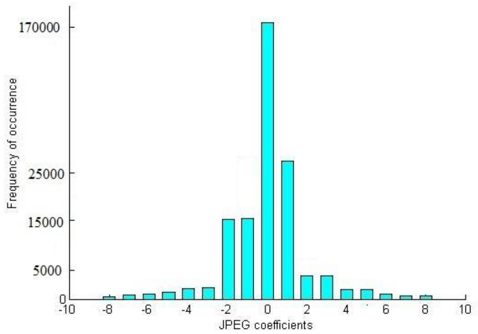


Fig. 3 The histogram of a stego image (Jsteg algorithm)

III. ISA ALGORITHM

The ISA algorithm embeds message bits by modifying the redundant bits in the cover medium (such as image, audio, or video). JPEG image format is the most widely used image format on the web, as a result, it is a good cover medium for information hiding. Modifying the Least significant bits of the nonzero AC discrete cosine transform (DCT) will be secured against visual attacks [14, 15]. An encryption key is needed to transmit the minimum number of each pair of values PoVs, so more message bits can be embedded to the DCT coefficients on the account of adding distortions to the first order statistical properties. After reaching the maximum limit of embedding, the rest of nonzero AC DCT coefficients will be divided into segments of equal length m. The LSB bits of the nonzero AC DCT will be modified to preserve the ration of even to odd DCT coefficients. A polarity bit is added to each segment to identify whether the data bits or its complements were sent [1].

The total number of all possible combinations of zeros and ones in a segment of length m are equal and is given by:

$$M = mx2^{m-1} \tag{7}$$

In each segments, there are zeros and ones, the idea is to maximize the ratio of even to odd coefficients to preserve the histogram of the DCT coefficients. Segments with more zeros than ones will be omitted, since the complement of these segments is used. The total number of all combinations of bits with value zero and one are given as:

$$M_0 = M - (m-k) \sum_{k=0}^{(m-1)/2} \binom{m}{k}$$
$$M_1 = M - k \sum_{k=0}^{(m-1)/2} \binom{m}{k} \tag{8}$$

Equation (7) gives the total number of all possible combinations of zeros and ones in a segment of length m. for the whole message, equation (8) can be considered as the average number of zeros and ones respectively. One can obtain the optimum segment length of the rest of nonzero AC DCT coefficients by comparing the ratio of zeros and ones to the ratio of even and odd DCT coefficients. The ratio R_0 of zeros to the total number of bits can be calculated as:

$$R_0 = M_0 / (M_0 + M_1) \tag{9}$$

The ratio R_0 with odd segment lengths increases with a step smaller than that with even segment lengths. However, the optimum segment length is only determined by checking the ratio of even to odd AC DCT coefficients of a given cover media.

A stego key that contains the minimum of every PoVs and the optimum segment length is sent with the secret message. Identify the message end by the word end of file.

A. Embedding Algorithm

1) Encrypt message bits with encryption algorithm.
2) Apply DCT transform and quantization for image compression in JPEG image format.

3) Find the minimum of each pair of values in DCT transform excluding the DC and the zero AC DCT coefficients.
4) Determine the maximum embedding capacity by adding up the results in step 3.
5) Calculate the optimum segment length m.
6) Embed the stego key.
7) Sequentially embed the message bits in the selected AC DCT coefficients.
8) If you don't reach the end of file word , embed in the rest of nonzero AC DCT coefficients.
9) Use Huffman coder for image encoding.

B. Extracting Algorithm

1) Decode the compressed image using Huffman Decoder.
2) Extract the stego key.
3) Convert odd coefficients into ones and even coefficients into zeros.
4) Append first the ones and zeros in the limited number of each PoVs
5) Stop decoding the message if you reach the end of file.
6) Repeat step 4 for the rest of DCT coefficients and append the extracted data into a file.
7) Decrypt the message bits using decryption algorithm.

In ISA technique, the maximum embedding capacity with preserved histogram depends mainly on the minimum in every pair of values (PoVs). Assume H is a one dimensional matrix representing the frequency of occurrence of DCT coefficients of a JPEG image and h_i is the frequency of occurrence of quantized value *i*, then

$$H = [\dots \; h_{-2}, h_{-1}, h_0, h_1, h_2, \dots] \qquad (10)$$

To fully utilize and divide the H matrix into integer number of PoVs, all nonzero AC DCT coefficients, the minimum and maximum quantized coefficients, should be even. The minimum and maximum values of quantized coefficients can be calculated as

$$h_{\min} = \begin{cases} \min(H) & \text{if } \min(H) \text{ is even} \\ \min(H)-1 & \text{otherwise} \end{cases} \qquad (11)$$

$$h_{\max} = \begin{cases} \max(H) & \text{if } \max(H) \text{ is even} \\ \max(H)+1 & \text{otherwise} \end{cases} \qquad (12)$$

And the total number of nonzero AC DCT coefficients n_{AC} is given by:

$$n_{AC} = N - n_{DC} - n_0 \qquad (13)$$

Where N is the total number of DCT coefficients, n_{DC} is the DC DCT coefficients, and n_0 is the zeros AC DCT coefficients.

After dividing the quantized AC DCT coefficients into integer number of PoVs, the maximum embedding capacity is limited by the lower value in every PoVs and can be calculated as:

$$C_p = \sum_i \left| \min(h_i, h_{i+1}) \right| \qquad (14)$$

And the embedding capacity of the rest of the AC DCT coefficients is given by:

$$C_r = n_{AC} - C_p \qquad (15)$$

The embedding efficiency is given by:

$$\eta = \frac{C_p + C_r(1-1/m)}{n_{AC}} \qquad (16)$$

IV. SIMULATION RESULTS

ISA algorithm preserves the histogram of frequency of occurrences as long as the message size doesn't exceed the maximum embedding limit C_p. As more data bits embedded to the cover medium, the histogram starts to show deviation from the histogram of the original image. Embedding data in the nonzero AC DCT coefficients are based on pairs of values method which means that every two adjacent coefficients can exchange values. The histogram of the DCT coefficients will be affected by the message bits when exceeding the maximum limit and this modifications can be detected [15, 16, 17].

Let's define D_{AC} as the difference between the cover medium and the stego medium histogram of the frequency of occurrence of DCT coefficients and define it as the change density and M_m as the message size in bits. For $M < C_p$ the change density will be zero for $M > C_p$, the following relation can be hold:

$$D_{AC} = p_m \frac{M_m - C_p}{n_{AC}} x100 \qquad (17)$$

Where p_m is the probability that the messages bits is different from the LSB of AC DCT coefficients. For uniform distributed messages bits p_m=1/2.

The change density D_{AC} is zero, when the message size is within the limit of maximum limit. A comparison of change density between Inverting Steganographic Algorithm (ISA) and Jsteg and F5 algorithms based on the absolute value of changes made to the nonzero AC DCT coefficients of an image (Baboo image) [18] is shown in Fig. 4. DEA is a direct embedding algorithm which is a modified version of the Jsteg algorithm without any processing on the AC DCT coefficients and including the value one for embedding [19].

The state of the art algorithms that can be taken as a reference for measuring the performance of ISA algorithm are Jsteg, Outguess and F5 algorithm. Since Outguess utilize only 50 % of the available capacity, it is not included in this comparison. From Fig. 4 it can be noticed that ISA algorithm doesn't affect the first order statistical properties of the standard test image until reach the maximum embedding limit determined by this techniques which in this case approximately 35 %. The optimum segment length is calculated for this image as 5 bits including the polarity bit.

Change density is calculated in this region based on the worst case scenario which is 40 % change density of the remaining nonzero AC DCT coefficients. The size of an image and its textural properties affect the maximum limit of embedding data bits using different steganographic systems.

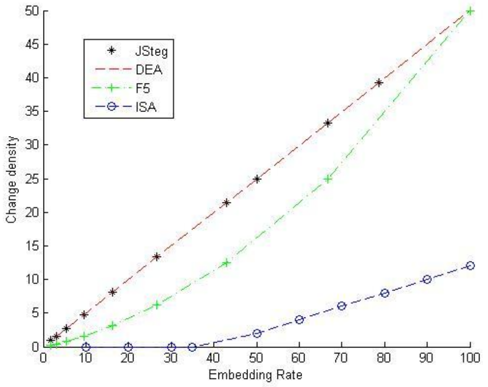


Fig. 4. A comparison between ISA algorithm and DEA, Jsteg and F5 algorithm

There is a tradeoff between the capacity of embedding and change density; the maximum capacity required the maximum change density will be introduced to the histogram. Fig. 5 shows some standard test images of size 512x512 of different textural properties used for capacity measurements. ISA algorithm offers high capacity with minimum change density as shown in Table 1.

Fig. 5. Standard test images from left-top Barbara, Boat, Camera man, and Jungle and from left- bottom Lena, Living room, Mandrill, and Pirate

TABLE I: CAPACITY MEASUREMENTS (IN BITS) USING VARIOUS EMBEDDING ALGORITHMS

Test images	Capacity in bits			
	ISA	Jsteg	F5	Outguess
Barbara	52059	40050	39892	20025
Boat	57299	41966	45229	20983
Camera man	27569	22572	20393	11286
Jungle	92815	71522	68853	35761
Lena	35621	28035	26992	14017
Living room	41028	34041	31025	17020
Mandrill	33847	26555	25990	13277
Pirate	41185	34126	31201	17063

From Table I, one can notice that the ISA algorithm outperforms the current existing algorithm. The ISA algorithm is divided to two parts one is the inverting technique and if more data bits to be embedded, the rest of the nonzero AC DCT coefficients are divided into segments of equal length to equalize the even to odd ratio of the cover medium. This technique defeats both visual and first order statistical attacks.

V. CONCLUSION

ISA algorithm outperforms current existing steganographic systems and can not be detected in both visual and statistical attacks. The histogram of frequency of occurrence of AC DCT coefficients is preserved if the maximum embedding capacity is limited to the lowest of the values of each pair of values PoVs. This technique minimizes the changes introduced to the first order statistical properties of the cover media due to message embedding by preserving the even to odd ratio for large message embedding.

REFERENCES

1. Hamdy A. Morsy, Zaki B. Nossair, Alaa M. Hamdy, and Fathy Z. Amer, "Utilizing Image Block Properties to Embed Data in the DCT Coefficients with Minimum MSE," *International Journal of soft computing and Engineering* vol. 1, no. 4, pp. 449-453 , 2011.
2. Hamdy A. Morsy, Zaki B. Nossair, Alaa M. Hamdy, and Fathy Z. Amer, " Optimum segment length for embedding in the LSB of JPEG images with Minimum MSE," *International Journal of Computer and Electrical Engineering* vol. 3, no. 3, pp. 72-77 , 2011.
3. A. Kerckhoffs, "La Cryptographie Militaire", *Journal des Sciences Militaires*, 9th series, IX pp 5–38; Feb. pp 161–191, Jan. 1883.
4. R. J. Anderson, and F.A. Petitcolas, " On the limits of Steganography," *J. Selected Areas in Comm.*, vol.16, no. 4, pp. 474–481, 1998.
5. Mehdi Kharrazi, Husrev T. Sencar, and Nasir Memon " Image Steganography: Concepts and Practice," WSPC/Lecture Notes Seriesm, April 22, 2004.
6. A. Westfeld, "F5—A Steganographic Algorithm High Capacity Despite Better Steganalysis," *Springer-Verlag Berlin Heidelberg*, 2001.
7. N. Provos, and P. Honeyman, "Detecting Steganographic Content on the Internet," *CITI Technical Report* 01-11, 2001.
8. N. Provos, and P. Honeyman, "Hide and Seek: An introduction to steganography," *IEEE Computer security* 15407993/03, 2003
9. A. Westfeld, "Detecting Low Embedding Rates, ", 5th *Information Hiding Workshop.* Nooerdwijkerhout, Netherlands, Oct. 7−9, 2002
10. *A. Westfeld, and A. Pfitzmann, "Attacks on Steganographic Systems,"* in Andreas Pfitzmann (ed) Information Hiding. Third International Workshop, *LNCS 1768,* Springer- Verlag Berlin Heidelberg. *pp. 61–76. 289, 291, 293, 299, 2000.*
11. C. Hung, "PVRG-JPEG Codec, 1.1," Stanford niversity, 1993. http://archiv.leo.org/pub/comp/os/unix/graphics/jpeg/PVRG 291.
12. Manoj Kumar Meena, Shiv Kumar, Neetesh Gupta " Image Steganography tool using Adaptive Encoding Approach to maximize Image hiding capacity" IJSCE Volume-1, Issue-2, May 2011
13. C. Cachin," *An Information-Theoretic Model for Steganography*," *Cryptology ePrint Archive,* 2002.
14. N. Memon, and M. Kharrazi, "Performance study of common image steganography," *Journal of Electronic Imaging* 15(4), 041104 (Oct-Dec), 2006.
15. G. Cancelli, and M. Barni, "New techniques for steganography and steganalysis in the pixel domain, ", Ph.D. dissertation - Ciclo XXI. Report 2000 /028, 2009. www.zurich.ibm.com/˜cca/papers/stego.pdf.
16. T. Pevn'y, J. and Fridrich, "Benchmarking for Steganography," *Information Hiding.10th International. Workshop,* Santa Barbara, CA, LNCS vol. 5284, 2008.

17. D. Upham, "Steganography software for Windows," 1997, http: //members.tripod.com/steganography/stego/ software.html
18. J. Fridrich, M. Goljan, and D. Hogea, "new methodology for breaking steganographic techniques for JPEGs," *in Proc. of SPIE: Security and Watermarking of Multimedia Contents*, vol. 5020, pp 143–155, 2003.
19. *Jan Kodovský, Jessica Fridrich "Quantitative Steganalysis of LSB Embeddingin JPEG Domain" MM&Sec'10, September 9–10, 2010, Roma, Italy.2010 ACM 978-1-4503-0286-9/10/09*

AUTHORS PROFILE

Hamdy A. Morsy is a PhD student at Faculty of Engineering at Helwan University, Cairo, Egypt. He received his M.Sc. (2002) from Stevens Institute of Technology, Hoboken, NJ, USA. He is currently working as a senior teaching assistant at faculty of engineering at Helwan University.

Zaki B. Nossair received his B.Sc. in electronics and communications engineering, Helwan University (1978) and M.Sc. in electrical engineering (1985), Stevens Institute of Technology, NJ, USA. His PhD in electrical engineering, Old Dominion university , Norfolk, Virginia, USA, 1989. He is currently an associate professor at Helwan University. His current research interests in the field of image processing, speech processing.

Alaa M. Hamdy received his M.Sc. degree in computer engineering from Helwan University in1996 and his PhD degree from the faculty of electrical engineering, Poznan University of technology, Poland in 2004. Currently he is an assistant professor at faculty of engineering, Helwan University. His research interests in the field of image processing, pattern analysis and machine vision.

Fathy Z. Amer is the professor of Electronics in the department of Communications and Electronics, Helwan University, Cairo, Egypt. Previously, He was an associate professor at faculty of training at El ahsaa, Saudi Arabia from 1995 to 2004. His research interests include Microelectronics and Testing and Information Hiding.