

Watermark Compression in Medical Image Watermarking Using Lempel-Ziv-Welch (LZW) Lossless Compression Technique

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Abstract In teleradiology, image contents may be altered due to noisy communication channels and hacker manipulation. Medical image data is very sensitive and can not tolerate any illegal change. Illegally changed image-based analysis could result in wrong medical decision. Digital watermarking technique can be used to authenticate images and detect as well as recover illegal changes made to teleradiology images. Watermarking of medical images with heavy payload watermarks causes image perceptual degradation. The image perceptual degradation directly affects medical diagnosis. To maintain the image perceptual and diagnostic qualities standard during watermarking, the watermark should be lossless compressed. This paper focuses on watermarking of ultrasound medical images with Lempel-Ziv-Welch (LZW) lossless-compressed watermarks. The watermark lossless compression reduces watermark payload without data loss. In this research work, watermark is the combination of defined region of interest (ROI) and image watermarking secret key. The performance of the LZW compression technique was compared with other conventional compression methods based on compression ratio. LZW was found better and used for watermark lossless compression in ultrasound medical

images watermarking. Tabulated results show the watermark bits reduction, image watermarking with effective tamper detection and lossless recovery.

Keywords Teleradiology · Ultrasound medical image · Compression · Digital watermark · LZW lossless compression · Secret key

Introduction

Digital imaging technology has got importance due to its immense uses in every field of life, especially in medical. This technology has made possible transformation of real-world images to computer-understandable formats called digital images. Medical imaging is a very important part of digital imaging used for medical and surgery planning in the health recovery process. Different medical imaging modalities such as magnetic resonance imaging (MRI), ultrasound (US), computed tomography (CT), X-ray, electrocardiography (ECG), etc. are being used for medical imaging. Each modality has its imaging advantages and limitations. The advantages and limitations play an important role in the achievement of dedicated purposes or become an obstacle in their performances. Demand of life facilities is increasing as compared to increase in population of the world. One of such demands is the provision of healthcare facilities for every one and every where. Telemedicine is a computer networks-based healthcare facility being developed to facilitate people of remote areas of a country. Teleradiology is an important unit of telemedicine used to communicate medical images from one location to another for better diagnosis. From the beginning, digital communication technology is not trustable for secure online image communication due to communication media noises and hacker manipulations. Therefore, medical image security has

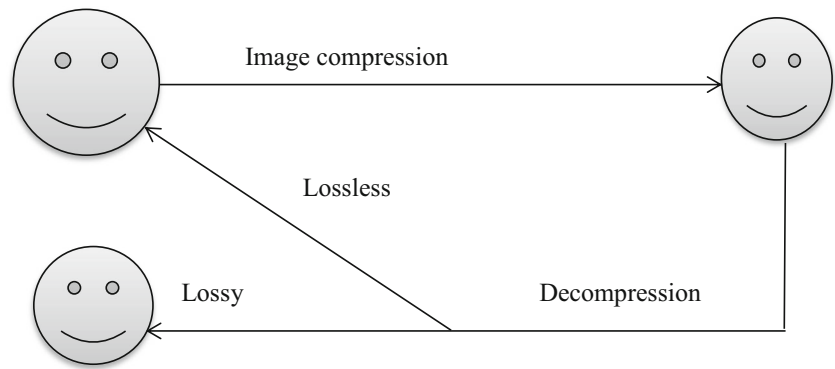
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Fig. 1 Image compression

the key importance in teleradiology. Although a number of data security techniques are used but medical image security still needs to be improved to address the security challenges. Firewall, certificate services, encryption, virtual private network (VPN) and steganography are some of well-known data security techniques operational in practical environment. These techniques with some of their inherited versions like digital signature (DS), manipulation detection codes (MDCs) and machine authentication codes (MACs) are useful for on-line data security other than sensitive data security such as medical images. Mostly, these techniques report only for data alterations but have no capabilities to correctly locate and restore the altered portion of the data. Medical image data is very sensitive and needs bit to bit originality. Digital watermarking is one of data security techniques under development to provide better security to medical images in teleradiology [1].

Digital watermarking is the process of embedding relevant information to a digital image as watermark for copyrights protection, authentication, tamper detection and recovery [2–4]. A number of watermarking techniques have been developed for online communicating medical images. Broadly, these techniques are divided into two main classes, namely frequency and spatial domains [5, 6]. In frequency domain watermarking, the watermark is not directly embedded to image but embedded to its signal form. Three popular transformation techniques, discrete cosine transform (DCT), discrete fourier transform (DFT) and discrete wavelet transform (DWT), are used for this purpose. This category of image watermarking is complex due to image transformation to signal form. The main advantage of this category is watermark robustness to attacks such as cropping, scaling, etc. but has low payload embedding capacity.

In spatial domain watermarking, the watermark is directly encapsulated to image without conversion to some other form. This category of watermarking is fast and simple due to image non-conversion process. Spatial watermarking has better capacity of watermark payload embedding but lack of watermark security is the main problem in presence of attacks.

These attacks can make watermark useless. Many watermarking methodologies have been developed to perform spatial domain watermarking. Some of the methodologies are reversible, irreversible; tamper detection and recovery; tamper localization and lossless recovery [1]. Most of the methodologies have been applied to medical images to maintain the originality of teleradiological images. Heavy payload watermark embedding causes image perceptual degradation and shortage of enough embedding capacity problems. To maintain the image perceptual quality constant and improve the embedding capacity, watermark compression is useful [7–9]. Least significant bits (LSBs) manipulation-based fragile watermarking technique is used to control watermarked image degradation and content authentication [10].

Data compression is a technique applied to text, audio, video and image data for elimination of redundant elements [11]. Lossy and lossless are two categories of data compression. Lossy compression is also known as irreversible compression; it can be used to compress data up to a range of 10 to 50 times the original size with loss of some data permanently [12, 13]. Transform coding techniques such as wavelet transform and cosine transforms are efficient for such types of compressions [14]. Lossless compression also known as reversible compression is the one which reduces data size in a ratio 10:1 without any loss [15, 16]. Sensitive data such as medical images, military data, facts-based tabulated numbers, programming codes and word processing files require strictly lossless compression to maintain their absolute originality [17].

Figure 1 describes a general digital image compression. It shows the fact that a compression reduces image size to be easily processed. On decompression, if the compressed image results in the same as to the original one then this is lossless; otherwise, the compression is lossy. During our experiments, we used lossless compressed watermark to get it back at destination in original status after decompression to perform authentication, alter detection and recovery process.

Literature related to image data compression reports a number of approaches used for lossy and lossless compression. Artificial neural networks (ANNs) perform image parallel compression and reduce compression time

[18–21]. ANNs are used for lossless compression of digital images [22, 23]. A hybrid compression algorithm, arithmetic encoding and transform coding have been used for image data compression [24–27]. Different conventional methods are used in image processing such as portable network graphics (PNG), graphic interchange format (GIF), portable bitmap (PBM) and joint photographic expert group (JPEG) to store images in specific formats.

Hospital information system (HIS) and picture archiving and communication system (PACS) are using DICOM formats for medical image processing in their compressed versions [28]. Dictionary-based data compression algorithms have been used for image and text data compression. Dictionary-based data compression approaches are divided into different classes; every class compression is producing their respective code tables. The repeated sequences data elements in image file

Fig. 2 LZW compression flowchart

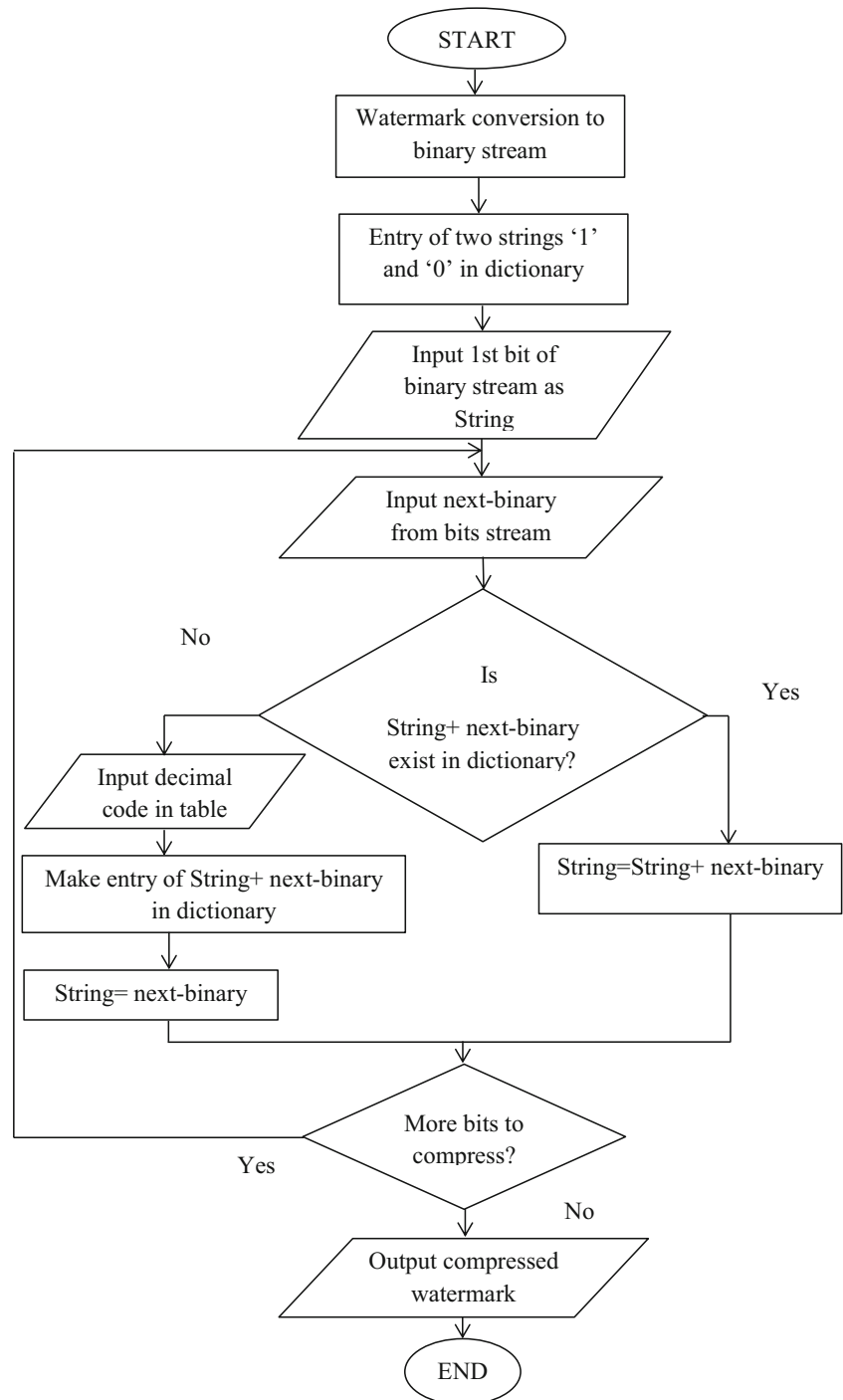
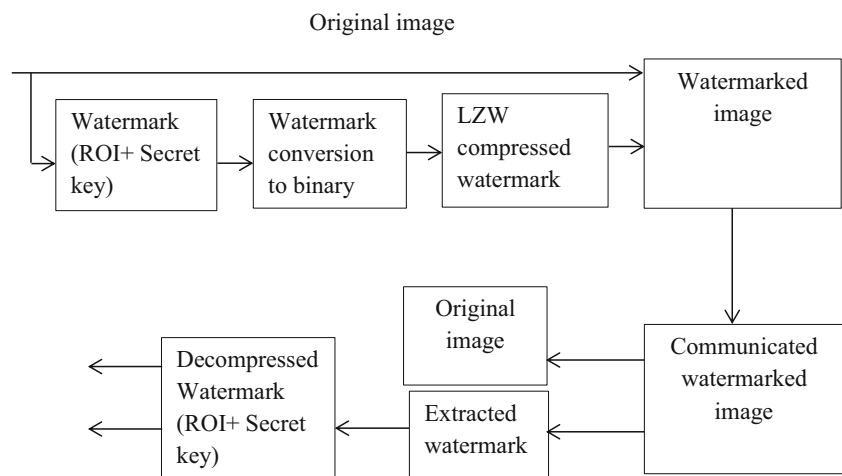


Fig. 3 Image watermarking, communication, watermark extraction and decompression



are replaced by short codes to reduce data size [29–31]. The Lempel-Ziv-Welch (LZW) approach is a dictionary-based lossless compression technique capable of image and text data lossless compression, as shown for binary image in Fig. 2. Watermark lossless compression in medical image watermarking is the way to control image degradation by reducing watermark payload [32, 33]. In this research work, we use LZW technique for watermark lossless compression in ultrasound medical image watermarking as shown in Fig. 3.

Materials and Methods

In this research work, six different samples of ultrasound medical images are used for experiments as shown in Figs. 4, 5, 6, 7, 8 and 9. Each sample is divided into region of interest (ROI) and region of non-interest (RONI). ROI is the central and rich in information part while RONI is the remaining image. Here, watermark is the combination of image selected pixels as ROI

and secret key. For compression purpose, watermark is converted to a single row binary stream. This conversion gives binaries unique sequences for LZW effective compression. During compression, every unique sequence is replaced by a decimal number also called string code. This process continues till the whole binary stream is finished. Algorithm 1 and Fig. 2 show the stepwise process of watermark lossless compression. All the string codes collectively represent compressed watermark. To watermark the image, first, the compressed watermark is converted to binary. Watermark is applied to the image at RONI area pixels at the 1st and 2nd least significant bits (LSBs). The LSB modification for watermark insertion is decided to maintain the image perceptual and diagnostic qualities standard. At the destination during watermark extraction, the modified LSBs are accessed to retrieve the inserted bits. The retrieved bits are converted back to decimal codes and these decimal codes equalling binary sequences stored in the dictionary are accessed. The accessed binary sequences are combined to get back exactly the watermark binary stream as decompressed watermark. Algorithm 2

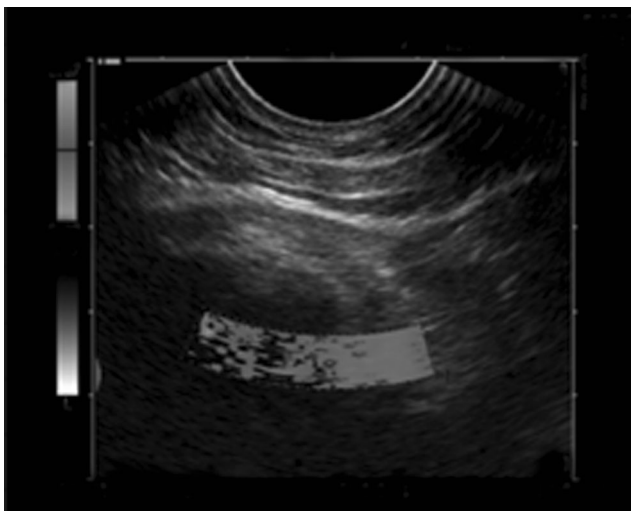


Fig. 4 Image sample 1

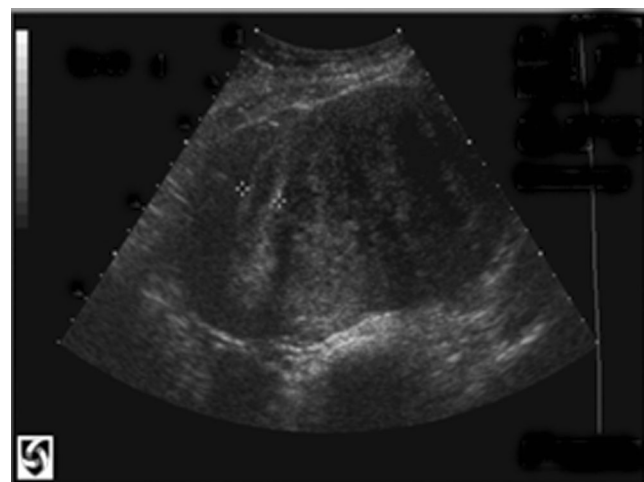


Fig. 5 Image sample 2



Fig. 6 Image sample 3

and Fig. 10 show the LZW lossless decompression in step by step process. Decompressed watermark is divided to ROI pixels and secret key. Secret key is used for ROI authentication and recovered ROI part of watermark is used for tamper detection and lossless recovery.

Watermark Preparation and Compression

A 100×100 size pixels segment of each image was selected as ROI. Secret key was generated and combined with ROI to obtain watermark. Watermark was compressed using the LZW lossless compression technique and embedded into image RONI part.

Lempel-Ziv-Welch (LZW) has been used for elimination of data repeating sequences [34–36]. We used this technique for watermark lossless compression in medical image watermarking. LZW lossless compression of watermark was compared with other conventional methods as shown in

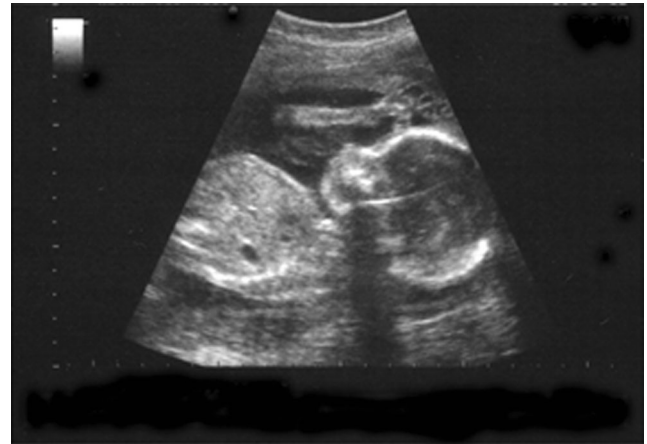


Fig. 8 Image sample 5

Table 1. More number of bits reductions makes LZW as the best choice for watermark compression in medical image watermarking. PNG, PBM, JPG and JPEG 2000 are conventional methods tested for the same size watermarks compression but LZW has the best of all compression ratios. Figure 2 shows graphical sketch of data flow during watermark lossless compression. Before starting watermark compression, the dictionary is initialized with two strings, i.e. '0' and '1'. These are only two possible values in watermark binary stream. Later on, during compression, unique strings are formed and inserted to the dictionary. During watermark compression, every binary repeating sequence is allotted a decimal code and inserted to another array called code table. LZW algorithm 1 checks the availability of a newly constructed string in the table. If the new generated codes and strings are unique then inserted in the code table and dictionary respectively as shown by example in the first part of 'Experiments and Results' section. This process of insertion continues till the whole watermark is compressed. The following algorithm 1

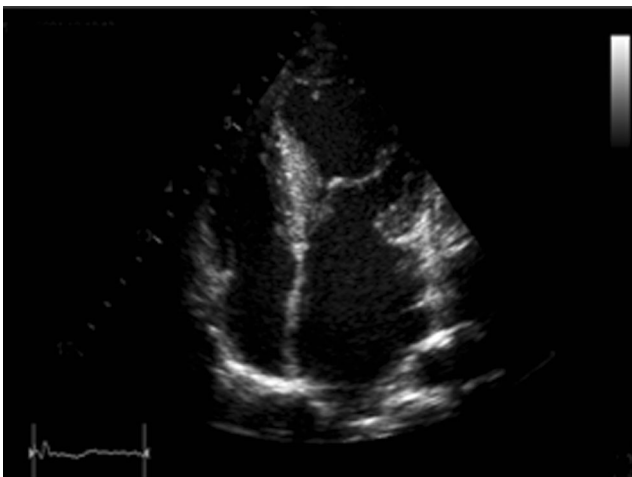


Fig. 7 Image sample 4



Fig. 9 Image sample 6

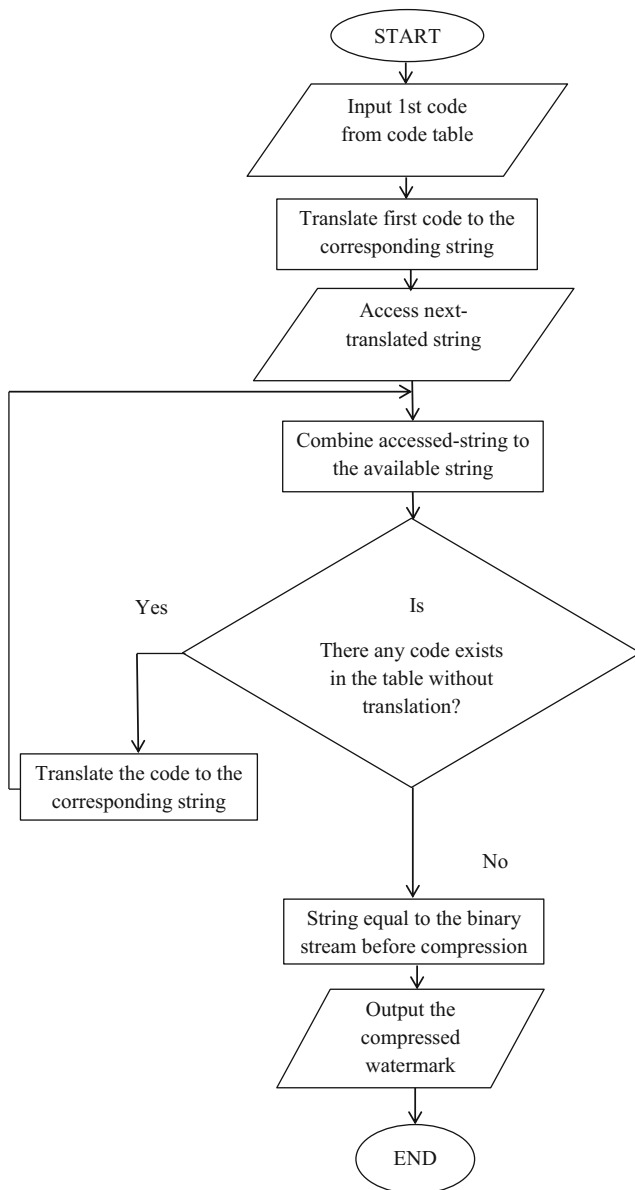


Fig. 10 LZW decompression flowchart

explains the step by step process performed during watermark lossless compression. The final dictionary and code table values are used for extracted watermark decompression [37].

Algorithm 1: LZW algorithm for binary watermark compression

1. Dictionary={ '0' , '1' }
2. String=Get the first binary from watermark binary stream
3. WHILE get the next available binary and continue
4. Next-binary=Get the next binary
5. IF String+Next-binary exists in the dictionary then
6. String=String+Next-binary
7. ELSE
8. Assign decimal code to String and insert into code table
9. Add String+Next-binary to the dictionary
10. String=Next-binary
11. End of IF
12. END of WHILE
13. Output dictionary and code table

Image Watermarking, Watermark Extraction and Decompression

Liew et al. [32] presented tamper localization and lossless recovery watermarking scheme for ultrasound medical images. They used image blocks as watermarks, inserted into images, which usually degrade the images' perceptual and diagnostic qualities. The watermarks were processed in jpeg2000 format for whole size reduction without reducing the number of bits. In our work, the use of LZW for watermark lossless compression reduces the number of bits. Watermark was encapsulated at two least significant bits of RONI pixels to maintain image perceptual and diagnostic qualities

Table 1 Comparison of watermark compression techniques based on compression ratio

Technique	Watermark compression ratio						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average
PNG	0.497	0.507	0.214	0.517	0.467	0.474	0.446
GIF	0.858	0.913	0.285	0.808	0.707	0.862	0.738
PBM	0.131	0.131	0.131	0.131	0.131	0.131	0.131
JPG	0.515	0.558	0.263	0.554	0.495	0.521	0.484
JPEG2000-j2c	0.441	0.446	0.290	0.446	0.446	0.424	0.415
JPEG2000-jp2	0.449	0.445	0.298	0.455	0.454	0.433	0.422
JPEG2000-j2k	0.441	0.446	0.290	0.446	4464	4245	0.415
LZW	0.087	0.088	0.035	0.021	0.036	0.061	0.054

fdb571d5a8bb6fefbf647d3e2a2cca67ef071fea6d8559cbcd09e0c65ef22ed1

Fig. 11 Watermarking secret key before image watermarking

unchanged. Figure 3 shows a sketch of watermark LZW lossless compression, encapsulation, image communication, watermark extraction, decompression, ROI authentication and lossless recovery. After watermarked image communication at the destination, watermark is extracted and decompressed. The watermark extraction and decompression are performed by applying the decompression algorithm 2. Figure 10 shows the LZW decompression of the extracted watermark. The extracted watermark is obtained in binary bits stream. These binaries are converted back to decimals to get back the equalizing binary repeating sequences stored in the dictionary. The recombination of these binary repeating sequences give uncompressed original watermark.

After the watermark lossless decompression, watermark exists in the state as it was before compression, without any data loss. Algorithm 2 describes main steps of LZW lossless decompression process of extracted watermark. The watermark decompression process is started from a null string definition. The code table values are accessed to get back binary repeating sequences from the dictionary. At the start, the first code equaling string is accessed. Same way the second code value equaling string is accessed and concatenated to the first code equaling string. On the same way, the third code equaling string value is concatenated to the previously combined string and so on. At last, all the codes and their equaling strings are accessed and a single row binary stream is obtained. This is the uncompressed watermark in binary. Figure 10 represents the data flow during LZW lossless decompression of watermark.

Algorithm 2: LZW decompression algorithm for extracted watermark.

1. String-processed=NULL
2. Set Counter
3. Consider the first string of the dictionary
4. Counter=Counter+1
5. While loop there are still Codes to process Do
6. Read New Code
7. String=String+New Code corresponding string in the dictionary
8. Output String
9. Update Counter
10. Add Old Code+string to the codes table
11. Old Code=New Code
12. End of While loop

1db571d5a8bb6fefbf647d3e2a2cca67ef071fea6d8559cbcd09e0c65ef22ed1

Fig. 12 Watermarking secret key after extracted watermark decompression

The uncompressed watermark is consisting of two major portions, secret key and recovery parts. The secret key is used for ROI authentication and the second portion gives the ROI pixels to be used for ROI tamper detection and lossless recovery.

Experiments and Results

This section contains the experimental results and their detail discussion. Out of six samples of ultrasound medical images here we only describe results of sample 1, a 480×640 size image dictionary and codes table values are partially listed below. ROI size=100×100, secret key length=64 values and uncompressed watermark total number of elements as binary stream=80,256 values.

(11111101101010101110001110101011010100010 . . .
100110001001010010001100 . . .)

Initialized dictionary={‘0’, ‘1’}

Updated dictionary={‘0’, ‘1’, . . ., ‘0110001001100’,
‘001001010010001’, ‘110001111100’, . . .,
‘101101011111’, ‘1011001000110011’, ‘1101101000011’, .
. . .}

Total number of compressed watermark elements as decimal codes=6998 values

(1, 3, 4, 2, . . ., 13, 11, 7, 21, . . ., 55, 53, 88, . . ., 119, 164,
153, . . ., 6743, 6149, 5478, 174)

Compressed watermark as binary
ry=(000000010000010100000110 . . .)

PSNR of watermarked image=51.5351 dB,

PSNR of recovered image=recovered image is the same as the original image.

Authentication

Before the image watermarking and communication, the image watermarking key is created and made a part of watermark. After watermark extraction and decompression, the key is separated and used to know, is any tampering occurred at ROI or not. For better understanding, the secret key value as part of watermark before image watermarking and recovered value have been shown in Figs. 11 and 12 respectively. Both of the values are compared; if both are same, then it means the ROI is authentic. If secret key values are different as Figs. 11 and 12 show their difference at the 1st byte, it means tampering has occurred and tamper detection and recovery is necessary.

Table 2 PSNR of watermarked and recovered images in decibels

US image	Watermarked image	Recovered image
Sample 1	51.5351	Same as the original image
Sample 2	52.1544	Same as the original image
Sample 3	55.8521	Same as the original image
Sample 4	54.5892	Same as the original image
Sample 5	53.3211	Same as the original image
Sample 6	56.5321	Same as the original image

Tamper Detection and Lossless Recovery

Tamper is some illegal change to the image pixels which misleads the diagnostic process. In case of tamper occurrences, those pixels are located and recorded. To locate tamper, pixel to pixel comparison is made between the image ROI and recovered watermark recovery part. The image ROI tampered pixels are replaced by watermark recovery part original pixels. Peak signal to noise ratio (PSNR) is used to analyze the qualities of watermarked, tampered and recovered images. Table 2 shows the PSNR of watermarked, tampered and recovered images. The PSNR values show up to which level the image has been degraded. If the PSNR value is less than 30 dB, then the image is perceptually degraded and cannot be considered

for further analysis. Figures 13 and 14 show a summary of tamper detection and lossless recovery of ultrasound medical images sample 1 and 2. Both the samples were tampered by adding salt and pepper and cropping noises through the ImageJ software for testing purposes. As it can be seen from Figs. 13, 14 and Table 2, our watermarking scheme performs with 100 % accuracy the process of tamper detection and lossless recovery. Equations 1 and 2 give details of PSNR calculation, where I and I_w refer to the original and watermarked images respectively. $\text{MAX}(I)$ means the maximum possible intensity of a pixel; in our eight bits ultrasound medical images, it is 255. PSNR calculation needs a statistical function called mean square error (MSE) used to calculate the noise induced into image during watermark insertion.

$$\text{MSE} = \frac{1}{mn} \sum_{i=0}^m \sum_{j=0}^{n-1} [I(i,j) - I_w(i,j)]^2 \quad (1)$$

$$\text{PSNR} = 20 \cdot \log_{10}(\text{MAX}(I)) - 10 \log_{10}(\text{MSE}) \quad (2)$$

The watermark compression is necessary to reduce the number of bits in watermark payload, increase image embedding capacity and keep safe the watermarked image from perceptual degradation. A medical image watermark contains important data, so it must be lossless compressed to avoid such an important data loss. Different lossless

Fig 13 Tamper detection and lossless recovery of ultrasound medical image sample 1

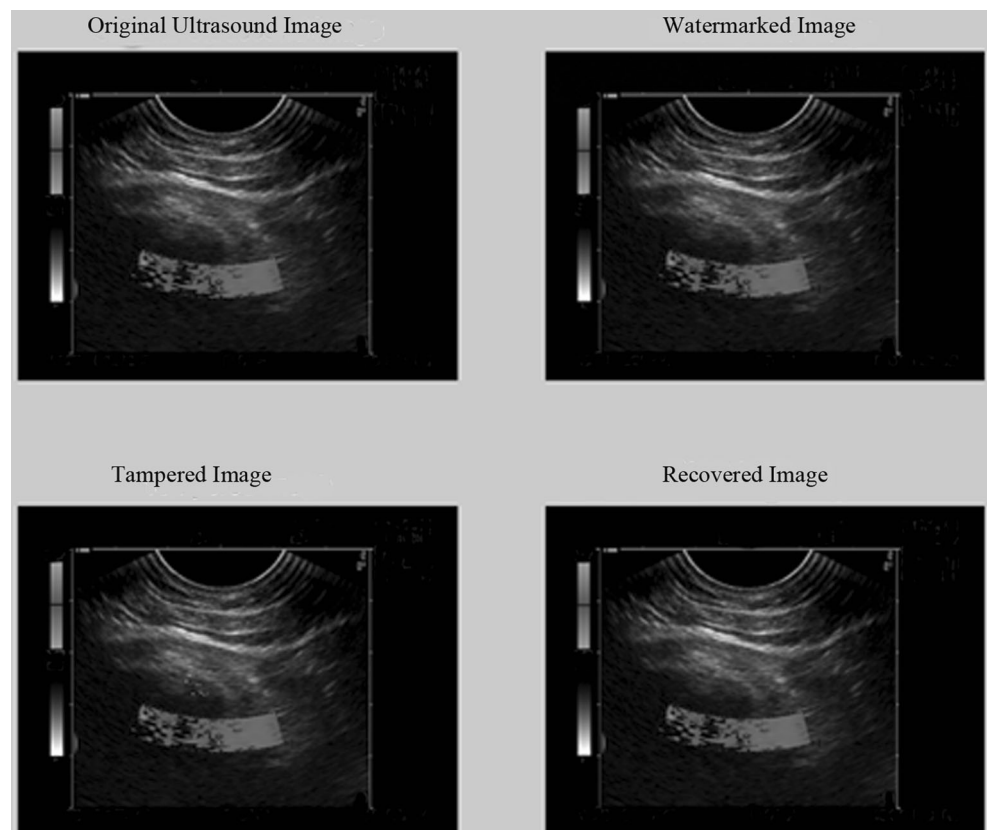
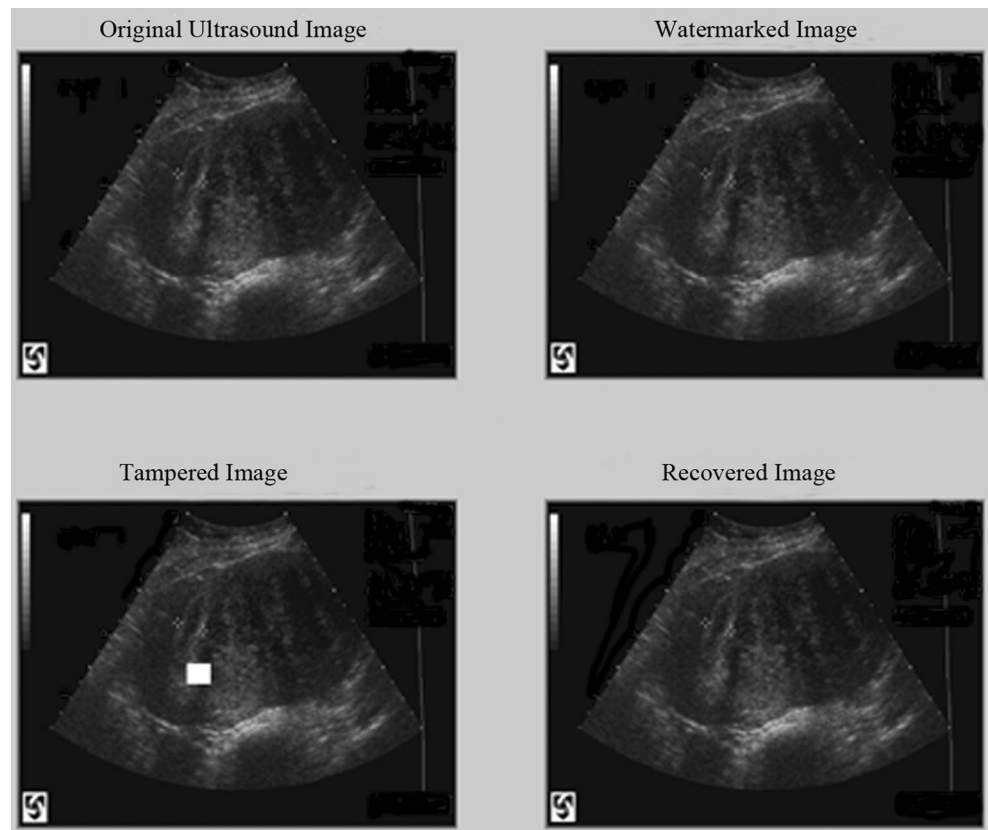


Fig 14 Tamper detection and lossless recovery of ultrasound medical image sample 2



compression techniques and conventional methods were tested for watermark compression. The results are shown in Table 1 for eight bits ultrasound medical image watermarks compression. LZW gives the best compression ratios as compared to the other conventional methods. Compression ratio is the ratio of the number of compressed bits to the number of uncompressed bits. Table 2 lists the results of watermarked and recovered image qualities. We used MATLAB R2010a, Windows 7 Professional and HP Intel® Core (TM) i7-3770 CPU @3.40GHZ for our watermarking algorithms testing and obtaining the tabulated results.

Discussion and Conclusion

Medical image security is an important factor in the online healthcare system. Digital watermarking is one of the security techniques, can be used for image security. The addition of heavy data to an image as watermark causes image perceptual degradation. As a result, image perceptual degradation affects the patient diagnosis. To keep the image safe from degradation and ensure true diagnosis, the watermark compression is suggested in literature. This compression must be lossless to ensure no loss to important and sensitive data because a minor change is also not tolerable in case of medical images. In this research work, the LZW lossless

compression technique has been used for watermark lossless compression. LZW lossless compression technique is better than other conventional compression methods for watermark lossless compression as evident from results listed in Table 1 for six ultrasound medical images. This is evident from Table 1, especially analyzing the average calculations in the last field that LZW has the best of all compression ratios near to zero and that is the feasible compression value because it shows more number of bits reductions, compared to all other compression techniques. Here, the image watermark is transformed to binary stream which gives repeating sequences of binaries. Replacing these repeated binary sequences by decimal codes results into reduced size watermark. If LZW is applied repeatedly, then theoretically the whole watermark size can be reduced to two binaries, a zero and one. The insertion of only two bits watermark to an image will definitely solve the image degradation and watermark accommodation problems permanently.

The recovered watermark is decompressed and used for ROI authentication, tamper localization and lossless recovery. Table 2 shows the watermarked and recovered images peak signal to noise ratio (PSNR) calculation to show their quality of degradation and reconstruction. First, the ROI is checked for its authenticity by comparing watermarking secret key values as shown in Figs. 11 and 12. If both the codes do not

match with each other, then tamper localization and lossless recovery is necessary. Similarly, if both the values are matched with each other, it means the ROI is authentic and the image can be used for further analysis.

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