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# Medical Image Watermarking

## Techniques and Applications

Springer

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# Preface

Information and communication technology (ICT) has been potentially useful for cost-effective and speedy transmission of electronic patient record (EPR) over open channels for telemedicine applications. However, attempts of malicious attacks or hacking for unauthorized access, alteration, modification, deleting, or even preventing the transfer of EPR possess challenging tasks in the implementation of dependable telemedicine systems. Therefore, the authenticity of EPR and related medical images is of prime concern as they form the basis of inference for diagnostic purposes. In such applications, tamperproofing and guaranteed originality of EPR/medical images is achieved by embedding some kind of watermark(s) which must be secure and robust against malicious attacks. Although numerous robust watermarking algorithms have been proposed, there has been a rat race situation between the robustness of watermark and malicious attacks, making robust watermarking an interesting challenging area for researchers.

In view of addressing the above challenges of telemedicine systems concerned with the authenticity and security aspects of transmitted EPR/medical image(s) over open channels for telemedicine, this book presents the state-of-the-art medical image watermarking techniques and algorithms for telemedicine and other emerging applications. The book begins with a conceptual introduction of digital watermarking, important characteristics, novel applications, different watermarking attacks, and benchmark tools followed by a detailed literature review on spatial and transform domain medical image watermarking techniques, their merits, and limitations. Subsequently, an in-depth analysis of available techniques of medical image watermarking is highlighted with their limitations. Further, the book presents improved/novel methods of watermarking for e-health applications which offer higher robustness, better perceptual quality, increased embedding capacity, and a secure watermark. For telemedicine, tele-ophthalmology, telediagnosis, and tele-consultancy services, medical images play a prominent role for instant diagnosis and understanding of crucial diseases as well as to avoid the misdiagnosis. In order to overcome this problem, the book includes some improved/novel medical image watermarking methods. The book also explores the important spatial and transform domain techniques followed by the major performance matrices. Finally, the book includes emerging trends and research challenges in robust watermarking and watermark security with special reference to telemedicine applications.

The authors believe that the book would provide a sound platform for understanding the medical image watermarking paradigm and prove as a catalyst for researchers in the field and shall be equally beneficial for professionals. In addition, the book is also helpful for senior undergraduate and graduate students, researchers, and industry professionals working in the area as well as other emerging applications demanding robust watermarking.

The book contains ten chapters. Chapter 1 presents a brief introduction of digital watermarking techniques, their classification, important characteristics, and emerging applications of digital watermarks followed by the essential requirements of medical image watermarking.

Chapter 2 contains a detailed review of the literature on medical image watermarking techniques and algorithms using medical image(s) as covers because they offer higher data embedding capacity. It includes both, the computationally simple but fragile watermarking in "spatial domain" and computationally expensive "transform domain" techniques that offer robust watermarking. The spatial domain watermarking using least significant bit (LSB) substitutions and the correlation-based and spread-spectrum techniques are discussed wherein the watermark data is embedded directly by manipulating the pixel values, bit stream, or code values of the host signal (cover media). The transform domain watermarking modulates the coefficients of a transform, e.g., discrete Fourier transform (DFT), discrete cosine transform (DCT), discrete wavelet transform (DWT), and singular value decomposition (SVD). Computationally complex transform domain watermarking techniques offer superior robustness of watermarked data as compared to spatial domain techniques. The chapter specially focuses on wavelet-based watermarking because it offers major benefits of space-frequency localization, multi-resolution representation, multi-scale analysis, reducing blocking artifact, adaptability, and linear complexity besides being compatible with JPEG 2000 image coding.

Chapter 3 describes detailed techniques of watermarking in spatial and transform domains along with major performance evaluation parameters: peak signal-to-noise ratio (PSNR), weighted peak signal-to-noise ratio (WPSNR), mean square error (MSE), universal image quality index, structural similarity index measure (SSIM), normalized correlation (NC), noise visibility function (NVF), and bit error rate (BER) of the watermarking algorithms. In addition, this chapter also discusses important watermark attacks and the use of a standard benchmark tool to measure the robustness of watermarking algorithms.

Chapter 4 presents a new robust hybrid watermarking technique using fusion of DWT, DCT, and SVD instead of applying these techniques individually or in combination thereof. It is based on initially decomposing the host image into first-level DWT followed by transformation of low-frequency band (LL) and watermark image using DCT and SVD. Then, the singular vector of the watermark image is embedded in the singular component of the host image, and the watermarked image is generated by inverse SVD on modified singular vector and original orthonormal matrices, followed by inverse DCT and inverse DWT. The proposed method has been extensively tested and analyzed against known attacks such as JPEG, Gaussian, Salt-and-Pepper, Speckle, and Poisson. The experimental results have revealed that the proposed technique achieves superior performance in respect of imperceptibility, robustness, and capacity as compared to the techniques reported in literature. Watermark robustness has been checked using the benchmarking software "Checkmark," and it is found that the suggested algorithm is robust against the "Checkmark" attacks. Further, the performance of the proposed watermarking method by applying encryption on patient text data before embedding the watermark has been investigated.

Chapter 5 addresses the issue of faulty watermark due to channel noise distortions which may result into inappropriate disease diagnosis in telemedicine environment. The effect of channel noise distortions in creating faulty watermark has been minimized by encoding the watermark using error correction codes (ECCs) before embedding. The effects of Hamming, BCH, Reed–Solomon, and hybrid ECC consisting of BCH and repetition code on the robustness of text watermark and the cover image quality have been investigated. It is found that the hybrid ECC code has better performance as compared to that of the other three codes, and the suggested method is robust against known attacks without significant degradation of the cover image quality. Further, the performance of the proposed watermarking method by applying Reed–Solomon ECC on encrypted patient data before embedding the watermark has been presented. The robustness of this method has been checked using "Checkmark" and is found that the proposed method is robust against the "Checkmark" attacks.

Chapter 6 discusses the solution to the growing concern of medical identity theft. This is based on the development of new secure watermarking techniques of medical data/image using multiple watermarking where patient identity reference and telemedicine center logo are used as text watermark and image watermark, respectively, for identity authentication. The embedding of watermark is based on DWT and spread-spectrum where pseudorandom noise (PN) sequences are generated corresponding to each watermark bit of the image watermark. The spread-spectrum has been used to secure the image watermark, and enhancement in robustness of the text watermark has been achieved using BCH-based ECC before embedding. The performance of this watermarking method has been tested against known attacks. Subsequently, simultaneous embedding of three watermarks, i.e., doctor code, image reference code, and patient record using multilevel watermarking of cover medical image, has been proposed to address the issues of data security, data compaction, unauthorized access, and tamperproofing. The suggested method uses wavelet-based spread-spectrum watermarking where the encrypted text watermarks are embedded at multiple levels of the DWT sub-bands of the cover image. The performance of the developed scheme is evaluated and analyzed against known attacks by varying watermark sizes and the gain factor. It is reported that the suggested multilevel watermarking enhances the security of the patient data and thus it can be potentially useful in the prevention of patient identity theft.

In chapter 7, the authors proposed new secure multiple watermarking techniques using eye image as cover for secure and compact medical data transmission in teleophthalmology applications. The method is based on initially embedding of four different watermarks using fusion of DWT and SVD. A secure hash algorithm (SHA-512) is used for enhancing the security feature of the proposed watermarking technique. The performance in terms of "NC" and "BER" of the developed scheme is evaluated and analyzed against known signal processing attacks and "Checkmark" attacks. The method is found to be robust against all the considered attacks.

Chapter 8 contains an algorithm for multiple watermarking based on DWT, DCT, and SVD which can be extremely useful in the prevention of patient identity theft in medical applications. The proposed method uses three different watermarks in the form of medical lump image watermark, doctor signature, identification code, and diagnostic information of the patient as the text watermark for identity authentication purpose. In order to improve the robustness performance of the image watermark, back propagation neural network (BPNN) is applied to the extracted image watermark to reduce the noise effects on the watermarked image. The security of image watermark is also enhanced by using Arnold transform before embedding into the cover. Further, the symptom and signature text watermarks are also encoded by lossless arithmetic compression technique and Hamming error correction code, respectively. The compressed and encoded text watermark is then embedded into the cover image. The experimental results are examined by varying the gain factor, different sizes of text watermarks, and different cover image modalities. The results are provided to illustrate that the proposed method is able to withstand different signal processing attacks and has been found to give an excellent performance for robustness, imperceptibility, capacity, and security simultaneously. The robustness performance of the method is also compared with other reported techniques. Finally, the visual quality of the watermarked image is also evaluated by the subjective method. This shows that the visual quality of the watermarked images is acceptable for diagnosis at different gain factors.

In chapter 9, the authors presented a robust and secure multiple watermarking method using a combination of DWT, DCT, SVD, selective encryption, error correcting codes, and neural network. The proposed technique initially decomposes the host image into third-level DWT where the vertical frequency band at the second-level and low frequency sub-band at the third-level DWT are selected for embedding image and text watermark, respectively. Further, the proposed method addresses the issue of ownership identity authentication; multiple watermarks are embedded instead of a single watermark into the same multimedia objects simultaneously, which offer the extra level of security and reduced storage and bandwidth requirements in important applications areas. Moreover, the robustness image watermark is also enhanced by using "BPNN," which is applied on extracted watermark to minimize the distortion effects on the watermarked image. In addition, the method addresses the issue of channel noise distortions in identity information. This has been achieved using ECCs for encoding the text watermark before embedding into the host image. The effects of Hamming and BCH codes on the robustness of personal identity information in the form of text watermark and the cover image quality have been investigated. Recently, selective encryption is computationally fast for large size multimedia documents offering secure document dissemination for various multimedia applications. In order to reduce the computation time and enhance the security of the documents, selective encryption is applied on watermarked image, where only the important multimedia data is encrypted. The proposed method has been extensively tested and analyzed against known attacks. Based on experimental results, it is established that the proposed technique achieves superior performance in respect of robustness, security, and capacity with acceptable visual quality of the watermarked image as compared to reported techniques. Finally, we have evaluated the image quality of the watermarked image by subjective method.

Finally, chapter 10 discusses the recent trends and potential research challenges of the state-of-the-art watermarking techniques in brief. It includes medical image watermarking, 3D model watermarking, watermarking in cloud computing and multi-core environment, biometric watermarking, watermarking using mobile device, and securing online social network contents. The chapter also reviews several aspects about digital watermarking in different domains. Meanwhile, it discusses the requirements and potential challenges that the watermarking process faces.

This book is an extension of the Ph.D. thesis of Dr. Amit Kumar Singh submitted to the Department of Computer Engineering, National Institute of Technology (Institution of National Importance), Kurukshetra, Haryana, 2015, under the supervision of Dr. Mayank Dave and Prof. Anand Mohan.

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# Contents

# List of Abbreviations

| | |
|---|---|
| AES | Advanced Encryption Standard |
| ASCII | American Standard Code for Information Interchange |
| BCH | Bose, Chaudhuri, and Hocquenghem |
| BER | Bit error rate |
| CDMA | Code division multiple access |
| CS | Compressed sensing |
| DCT | Discrete cosine transform |
| DFT | Discrete Fourier transform |
| DIBR | Depth-image-based rendering |
| DICOM | Digital Imaging and Communications in Medicine |
| DWPT | Discrete wavelet packet transform |
| DWT | Discrete wavelet transform |
| ECC | Error-correcting codes |
| EPR | Electronic patient record |
| GA | Genetic algorithm |
| HMM | Hidden Markov model |
| HVS | Human visual system |
| ICA | Independent component analysis |
| ICT | Information and communication technology |
| IWT | Integer wavelet transform |
| LSB | Least significant bit |
| LZW | Lempel–Ziv–Welch |
| MPEG | The Moving Picture Experts Group |
| MSE | Mean square error |
| NC | Normalized correlation |
| NROI | Non-region of interest |
| NVF | Noise visibility function |
| PCA | Principal component analysis |
| PN | Pseudorandom noise |
| PSNR | Peak signal-to-noise ratio |
| QF | Quality factor |

| | |
|---|---|
| ROI | Region of interest |
| SNR | Signal-to-noise ratio |
| SPIHT | Set partitioning in hierarchical trees |
| SVD | Singular value decomposition |
| SVM | Support vector machine |
| WBCT | Wavelet-based contourlet transform |

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