Chapter 7

Summary

Digital watermarking is a technology with many different application domains. Its potential in providing value-added services towards secure and efficient health data management is yet to be fully realized, because of the unique requirements of medical images. Watermarking of medical images must satisfy stringent fidelity requirements to ensure diagnostic quality. The main requirements are low distortion, high capacity and high security. Meeting all the three requirements simultaneously is usually infeasible; thus, trade-offs are frequently made to optimize the balance for each specific application. For added security, the original medical data may not be transmitted. In such cases, blind detection of the watermark without any prior knowledge about the original medical data is desirable. These specific problems associated with medical images demand the development of novel algorithms for medical image watermarking to enhance the quality and security of teleradiology.

It is widely accepted that robust image watermarking technique should largely exploit the characteristics of Human Visual System (HVS) to ensure the imperceptibility of embedded watermarks. The DWT provides superior modeling of the HVS, because of its excellent space-frequency localization of salient image features. This thesis explores the application of the multiresolution characteristics of wavelet transform to embed watermarks at different sub-bands, exploiting the limited ability of HVS to detect high frequency signals. The DWT-based approach is to produce watermarked images with the best tradeoff between transparency and robustness. In addition, the sparse and compact nature of the wavelet operators is exploited to achieve computational efficiency.

Like most other engineering problems, the design of suitable watermark embedding strength involves multiple, often conflicting, design criteria and specifications. Finding an optimal embedding strength is, therefore, not a simple task. Consequently, there is a need for optimization-based methods that can be used to obtain optimal embedding strength that would satisfy the conflicting requirements. Ideally, the
optimization method should lead to the global optimum of the objective function. GA has been widely used to achieve optimal solution in multidimensional nonlinear problem of conflicting nature. Hence, this thesis addresses the challenges of medical image watermarking by using GA to obtain the optimized solution based on a multiobjective fitness function, because of the ability of GA to work with a population of solutions, simultaneously, to find global solutions to a problem.

Based on the above reasons, this thesis explores the application of genetic algorithm and wavelet transform to develop novel algorithms to address the challenges of medical image watermarking. The algorithms developed are evaluated using real images of three different medical imaging modalities. For quantitative evaluation, image quality metrics such as the peak SNR, MSE and RMSE are computed to assess the fidelity and NC to assess the performance of robustness watermark to provide security, and fragile watermark to locate tamper.

Following a brief introduction to telemedicine, the advantage and application of wavelet transform and the crucial role of soft computing for regularizing the ill-posed problems in medical image watermarking are emphasized in Chapter 1.

In chapter 2, a generic model of digital watermarking system is developed. A detailed study of the principles and issues involved in digital watermarking is carried out. The transform domains for watermarking as well as the different type of watermarks are discussed. Chapter 2 concludes with the unique challenges medical image watermarking along with the scope and specific aims of the thesis.

In Chapter 3, based on a generic model for digital watermarking, a wavelet-based, robust, public key, blind watermarking scheme is developed to addresses the problems of confidentiality and security associated with teleradiology. The goal of this chapter is to exploit the advantage of public key encryption in wavelet domain to guarantee the security of the medical image. A pseudo-random sequence (key), related to hidden patient and physician information is embedded in the significant DWT coefficients of medical images of three different modalities. Encryption of watermark limits the chance of forging the watermarks. The design strategy of using symmetric algorithm, key concealing, and secure pseudo random selection of embedding data limits the scope of possible invertible, copy and cryptographic attacks, when compared
to classic watermarking schemes. Both subjective and objective methods are used to evaluate the watermarked image quality and the robustness of the watermark. Experimental results demonstrate that the watermarked images are robust to attacks, but at the same time show good fidelity, thus providing invisible watermark without any compromise on diagnostic reading. The normalized correlation value of ~0.85 indicates effective recovery and hence limited false alarms. Lifting wavelet scheme improves the computation speed by twofold. The algorithm takes advantage of the combination of the benefits using wavelet domain and encryption using a pseudo-random sequence (key). The subset selection of watermark, the novel idea that is proposed in the algorithm has the potential to limit the hacker’s success in the estimation of the original watermark data. Only a subset of the key is given for detection, and hence the attacker could not succeed in removing the mark completely.

One of the important requirements of medical image watermarking is to select an optimal embedding strength to make a reasonable trade-off between the two conflicting requirements of fidelity and robustness. The problem becomes more challenging, because medical images of different modalities have different noise characteristics. Even images of same modality, acquired under different environments differ in their noise characteristics. Not all watermarking methods are suitable for all image types and all applications. It is of interest to develop a knowledge-based approach for automated image-adaptive watermarking where the algorithm itself can select the embedding strength based on the input image characteristics. To address this issue, in Chapter 4, an innovative multiobjective GA-based, image adaptive wavelet domain watermarking algorithm, which optimizes the embedding strength to achieve an optimal trade-off between the conflicting goals of fidelity for diagnostics and robustness for security is presented. In this GA-based watermarking algorithm, the fidelity parameter, PSNR and the robustness parameter, NC are used to design the multiobjective fitness function.

Experiments using different types of medical images show that the GA-optimized embedding strength depends on the input image characteristics. In addition, it is also observed that the magnitude of embedding strength is different for different imaging modalities. An interesting result of this study is the insight into the trade-off
between fidelity and robustness. A multiobjective problem is reduced to the simple and computationally efficient single object problem using the weighted sum approach.

For enhanced information coding, medical images such as echocardiograms, fundus image and fMRI are color coded. A single watermark in the color image may fail to satisfy the conflicting interests of authenticity and integrity constraints of medical images. This motivated us to look for a dual watermark embedding algorithm that could meet the requirements of authentication and tamper detection in color images of different medical imaging modalities. For optimal embedding of the dual watermarks, two parameters, viz. the embedding strength of the robust watermark and the number of bits for embedding the semi-fragile watermark must be adaptively selected on the basis of the input image characteristics. To address this problem, a multi-gene approach, one gene coding for the embedding strength and other coding for the number of bits, is developed in Chapter 5. The algorithm is evaluated for its potential to preserve security and integrity, using color medical images. The L*a*b* color transform is selected to take advantage of its luminance masking effect as well as low compactness. Segregation of watermarking regions to achieve high level of watermark imperceptibility without incurring huge computational cost is an added advantage of this algorithm. Embedding the fragile watermark in LL sub-band ensures good performance in tamper detections.

The developed multi-objective, multi-gene, dual watermarking scheme addresses the problems of tamper detection and authentication for color echocardiograms as well as other color medical images. Both subjective and objective analyses of the experimental results indicate the efficiency of the proposed scheme, successfully fulfilling the compromise between robustness and image quality. The effectiveness of the semi-fragile watermark in tamper detection is proved under some general image manipulation attacks. Moreover, the scheme has a good accuracy in detecting and locating tampered blocks. The experimental results demonstrate the efficiency of the multi-gene approach by revealing that both the imperceptibility and authenticity of the medical image are retained. The application of L*a*b* color quantification and lifting wavelets helps reducing the computational complexity. By providing both robustness and fragileness, the dual watermarking algorithm guarantees the security and integrity of the medical images transmitted and/or stored.
The unavailability and high cost of communications services in rural and also in some urban communities act as major barriers to telemedicine. Compression of medical images offers a method of reducing the cost of storage and increasing the speed of transmission. But, compression should not compromise image fidelity. In addition, it is also essential to ensure that the compressed image has sufficient bandwidth to accommodate the watermark payload. In Chapter 6, for the first time, a novel algorithm which initially compresses the image by multiobjective GA and then embeds the watermarks in the compressed image by a multigene, multiobjective GA is developed. The GA-based image adaptive compression algorithm automatically selects a lower threshold value when the PSNR is low for the input image, thus finding an optimal solution for two conflicting objectives. This technique provides feasible way to obtain optimal compression ratio without compromising the image fidelity upon subsequent watermarking process. Two image processing applications, compression and watermarking are coupled to enhance the potential of watermarking in teleradiology, by exploiting the localization property of wavelet transform using genetic algorithm.

The algorithm is designed in such a way that the compression ratio and watermarking error can be controlled (near lossless compression and optimal watermarking). Experimental results show the ability of the system to detect tampering and to limit the peak error between the original and the watermarked images. Moreover, the watermarking is performed on a compressed image, the overhead for the watermarking process also becomes less due to the compactness of the compressed image.

One of a major concerns in the GA-approach used in this thesis is the additional computational overhead, which may however, can be addressed, exploiting the parallel nature of GA. Parallelization of GA can be done at various levels viz., distribution of fitness evaluation, distribution of population with migration of best individuals, distributed fitness evaluation within each subpopulation, and distribution of subgene within each chromosome. While the developed algorithms are tested to work on medical images from three different modalities, their use may readily be extended to other sensitive applications such as remote sensing, military application, video surveillance etc.
To conclude, medical image watermarking provides more options and promises for secure transmission and storage of medical data in teleradiology. However, despite its potentials, it is by no means a ‘cure-all’ solution for medical image security. The solutions are more likely to remain medical image modality-dependent. Further finding optimal trade-offs between the conflicting requirements of low distortion, robustness, high capacity, and speed continues to challenge real world application development. Before trustworthiness can be achieved, novel image-dependent, adaptive watermarking algorithms must be developed and evaluated using real images. This thesis makes a progressive step in this direction by exploiting the adaptive nature of GA and the multiresolution characteristics of wavelet transform. The successful application of the GA-based wavelet domain watermarking algorithms, developed in this work for watermarking of both gray and color medical images of various modalities, is likely to enhance research interest in teleradiology, a technology with great potential to bridge the gap in the quality of health care provided to the have and have-nots.