This chapter summarizes the major contributions of findings and the research activities reported in the present thesis. It also provides certain pointers for future research in various fields of the medical imaging computing paradigm.

6.1 Contributions

In this thesis work, certain aspects of medical image computing domain have been explored, existing problems have been identified and several feasible solutions have been proposed. Specifically, the major contributions of the present thesis work can be summarized as follows:

- Presence of different kinds of noise in various modalities of medical images, results in degradation in the image quality. Rician noise in MR images, often makes it difficult to properly analyze and interpret the acquired images. There exists several state-of-the-art MR image denoising methods based on different noise removal mechanisms. Recently, MR image denoising schemes based on the NLM paradigm, have gained popularity for their superior noise removal performance. But, NLM based MR image denoising techniques have one major shortcoming, i.e., high computational cost. Moreover, negative contributions of non-significant pixels in the denoising procedure also result in sub-optimal quality of denoised images. Most of the state-of-the-art
NLM based noise removal schemes for MR images, concentrate on either improving the denoising quality or reducing the computational burden. In Chapter 2 of this thesis, we have described a novel and alternate way to pre-select a subset of pixels in the non-local neighbors of NLM paradigm, depending on their similarities with the pixel of interest. The pre-selection of pixels is achieved by the time-matrix information of the noisy image obtained through PCNN with null interconnection. Denoised MR images, obtained by this introduced noise removal technique do not suffer from the problem of over-smoothing of fine textural and structural details, compared to existing denoising schemes. Experimental results and comparisons show that the pre-selection of significant pixels, through the use of synchronous pulse burst output property of PCNN results in faster computation without sacrificing the denoising performance of NLM.

- Most of the state-of-the-art MIF techniques suffer from various problems of image degradation like contrast reduction, blocking effects, blurring and loss of image details etc. Moreover, most of these schemes are modality and task specific. Keeping the above mentioned issues in mind, in Chapter 3 of this present thesis, we have used the shift invariance, multiscale and multidirectional properties of NSCT along with the global coupling and pulse synchronization characteristics of PCNN to develop two novel MIF schemes (termed as ‘Scheme 1’ and ‘Scheme 2’). These MIF techniques can capture the subtle differences as well as the fine details present in the source medical images into the fused image without reducing the contrast. In ‘Scheme 1’, the use of MSF (capable of efficiently representing the subtle directional details of the medical images) along with the use of different fusion rules for different subbands produces fused images with higher spatial resolution,
fewer unwanted degradations with lesser deviations from the source medical images. It has been observed from the obtained results and comparisons with state-of-the-art schemes that the fused images produced by ‘Scheme 1’ are more intelligible, more informative and have higher contrast which is very helpful for clinicians in their diagnosis and treatment planning.

In Chapter 3 of this thesis, we have also introduced another novel MIF method (‘Scheme 2’) based on a hybrid neuro-fuzzy approach in the NSCT domain. To overcome the drawbacks of the traditional MIF schemes, and to integrate as much information as possible into the fused images, we have exploited the advantages of the NSCT, RPCNN, and fuzzy logic. The linking strengths of the neurons in the RPCNNs are adaptively computed based on the fuzzy characteristics (reflecting the ambiguity of HVS response) of the image, which results in high-quality fused images. The parameter estimation problem of PCNN is handled by modifying the structure of PCNN (containing far fewer number of adjustable parameters) and adaptively setting the value of only the most impacting parameter (linking strengths). The experimental results show that ‘Scheme 2’ can preserve more useful information in the fused image with higher spatial resolution and lesser deviation from the source images.

- Chapter 4 of this thesis deals with the problem of ‘effective information retrieval’ from large and ever growing medical image repositories. In this chapter, two different solutions are provided for two different kinds of medical image search problems. In the first part of this chapter, we have described the benefits of the combination of MGA of RT, and a computationally less expensive SVM (LS-SVM) to build a fully automatic and accurate brain MR image classification system. With this combination, we not only have
achieved higher feature reduction, but also obtained superior performance than the state-of-the-art schemes. One of the major shortcomings of the existing brain MR image classification systems is their performance degradation in presence of common MRI artifacts (rotation, noise, different dynamic range, blurring etc.). Later in this chapter, an improvement of the aforementioned brain MR image classification scheme is described, which performs satisfactorily even in the presence of common MRI artifacts. This improvement is based on the use of both the LFS and HFSs information of the underlying transform domain. Moreover, we have also included a performance comparison study of several recently proposed transform domains like curvelet, contourlet and type-I ripplet. Comparative study of the performances of these transforms show that CNT performs superiorly considering both the classification accuracy and the dimension of the feature vector.

The second part of this chapter contains the description of a medical image retrieval system. From our experiments, we have noticed that NSCT based image coding is suitable for representing low level features of the medical images. Due to low feature vector dimension and use of LS-SVM classifier, the described CBMIR system is able to achieve satisfactory results with lower computational cost. Moreover, the proposed CBMIR system has been found to be general, in the sense that it works efficiently for different modalities of medical image databases.

- Digital watermarking has the potential of becoming an all-in-one solution tool to address various issues regarding effective and ethical management and distribution of medical information. In this regard, two different MIW schemes (termed as ‘Scheme 1’ and ‘Scheme 2’)) have been demonstrated in the last contributory chapter (Chapter 5) of this thesis. ‘Scheme 1’ is a
blind, fragile watermarking technique with good imperceptibility, high payload and enhanced security. This scheme can be used for different modalities of medical images. It can be applied to a variety of digital medical images with different size, format, and bit-depth. The tamper localization capability of ‘Scheme 1’ can successfully locate even a single tampered pixel and can detect the corresponding $3 \times 3$ block as the tampered region.

Storage and transmission of huge number of medical images and related information in a network environment has proven to be highly costly. This also requires special security measures to withstand different kinds of attacks, designed to destroy the integrity, authenticity, reliability and confidentiality of the critical and sensitive medical information. The ‘Scheme 2’ of Chapter 5, describes a blind, robust MIW technique with good imperceptibility and enhanced security. This method is not only robust against both high JPEG and JPEG2000 compression, but can also resist a large number of other watermarking attacks. The ‘Scheme 2’ can be used for different medical image modalities. The experimental results and comparisons with state-of-the-art MIW techniques, indicate that both the aforementioned MIW schemes are efficient and given their relative simplicity, they can be applied to medical images right after acquisition, to serve in many medical applications concerned with privacy protection, safety, archiving, access control, retrieval and management.

6.2 Future Work

Medical image computing paradigm is a rapidly expanding field and new challenges are arising everyday. The work reported in this present thesis is an attempt to solve certain problems of the medical image computing paradigm. Although
The solutions proposed in this thesis have been found to be useful and efficient, they need further investigations to be widely applicable in various medical image application domains. These may include theoretical analysis of performance, development of quantitative indices for evaluation, and study of sensitivity of the methodologies to noise. Some of the possible future extensions of the work presented in thesis are pointed out here.

- The MRI denoising scheme described in Chapter 2 can be incorporated with more improved version of the NLM filter to get superior results. Also, the extension of this denoising technique for 3D MR images should be carried out in future.

- In Chapter 3 of this thesis, main emphasis is given on fusion of multimodal (inter-modality) medical images. The demonstrated IF schemes may also be used for unimodal (intra-modality) medical image (with different configuration settings) fusion. The effects of different fusion rules, and new techniques to compute the parameters of PCNN, are also some of the future scope of research.

- The effectiveness of other feature representation schemes along with other supervised and unsupervised classification techniques should be investigated in future to improve the brain MR image classification scheme described in Chapter 5. The proposed image representative feature vector may also be used to classify other modalities of medical images. The retrieval accuracy of the proposed medical image retrieval system may be improved by incorporating relevance feedback mechanism into it.

- The spatial domain MIW scheme described in Chapter 5 can be improved to insert higher payload by making it independent of ROI’s size. This proposed MIW technique has the capability to localize tampering in the medical
images. Investigation is required to improve this MIW scheme by incorporating tamper correction capability. In the proposed transform domain MIW scheme, the value of $\alpha$ plays a vital role. The value of $\alpha$ is experimentally set in the proposed technique. It would be better if $\alpha$ can be set adaptively and automatically. Moreover, effectiveness of others transforms like curvelet, ripplet, non-subsampled contourlet can be tested to improve the results. Both the proposed MIW schemes may be improved by applying different insertion and extraction rules.

- This thesis contains several solutions only for gray-level 2D medical images. In future, these proposed solutions can be extended to work also on color and volumetric (3D) medical images. The use of the developed schemes in more real-life applications should be demonstrated. Finally, it would be worthwhile to study their implementation in hardware.