Chapter 7

Conclusion & Future Work

Medical Image Denoising plays a crucial role in Computer Aided Diagnostic (CAD) system where a good quality image can better be utilized in disease identification, segmentation of normal and abnormal tissues etc. This work started with some notion of segmentation and edge detection problems in medical images preceded by noise removal. The methods of noise removal in this thesis are revolving around utilizing the notion of uncertainty management using Rough Set Theory (RST). Although, RST has been used in past for segmentation purpose extensively, this is an early attempt to use it in image denoising framework as prior information.

This thesis interlinked uncertainty model defined by Rough Set in the image denoising framework where data is assumed to be corrupted by signal dependent noise. The prior information derived in RST framework is applied on three denoising frameworks. The spectrum of frameworks varies from pixel level aggregation to patch level aggregation and spread from bias correction to sparsity conditions.

This chapter summarizes the work accomplished in this thesis and discusses limitations and possibilities to extend it in various directions.
7.1 Winding Up

Being non-invasive technique, MRI offers a great help to diagnostic system by acquiring structural information of human anatomy. However, there is always a chance to get attenuated by various error sources, mentioned in Chapter 1. This thesis is an endeavor to use Rough Set Theory (RST [30]) explored to remove Rician noise model present in MRI. Main contributions of the thesis are listed below.

a. RST, being known for uncertainty handling capability, has been explored on noisy MR images. A novel multi-class thresholding method is proposed to generate Rough Class Label (RCL) and Rough Edge Map (REM) information. This scheme is adaptive in terms of number of objects present in the image and edges obtained here are closed and continuous. It also provides accessibility to visualize an object of interest and its boundary information.

b. A more informative denoising filter is proposed under Bilateral filter framework [35]. RCL and REM information are used to define a weighing term along with spatial and photometric weights for pixel based denoising mechanism.

c. The notion of non-local self similarity (NLSS) widen the use of similar neighborhoods in denoising instead of a pixel level processing in conventional methods. This is also generalized to patch based processing where two locationally far apart similar patches contribute to denoise each other. However, this process involves heavy computational burden. Under this situation, a clustering based framework is proposed which adhere to NLSS notion more appropriately. This provides a unique and more intuitive gathering of similar patches and then proceeds for denoising task. Hence, the number of computations get lowered down to an extent.

d. A non additive signal dependent Rician noise present in MRI makes the applicability of the natural image denoising methods unfair for MRI. However, this has been made possible by variance stabilization technique proposed in [2] to
an extent. To deal with above mentioned problem, a Kernel Principal Component Analysis (KPCA) based method with RCL and REM information has been proposed. The results laid a new direction to explore KPCA for signal dependent noisy environment.

e. Structure preserving property of previous proposal lays to explore it for 3D data denoising. The REM and RCL information are extended to explore relationship in 3D. Here, instead of dealing with patches, similarity criteria is redefined for voxels (cubes) and clustering based denoising framework is adopted as mentioned earlier. Kernel Principal Component Analysis (KPCA) indeed preserves structure, after denoising, better than its contemporary methods.

7.2 Contributions

This section gives a final glimpse of this thesis with an outline of the problem addressed in each chapter and solution addressed in that regard.

- The notion of Rough Set based class label and edge map information (i.e. RCL and REM) is defined in Chapter 2 using multilevel histogram thresholding and rough entropy optimization.

- REM and RCL are used as regularization factor in the Bilateral Filter to prevent distortion at edges in the noisy images in Chapter 3. The proposed filter can be regarded as Trilateral Filter.

- Patch based medical image denoising problem is addressed in Chapter 4. Rough Set based clustering approach is proposed for transformed domain based non-local MR image denoising problem.

- Kernel Principal Component Analysis (KPCA) method is adopted to deal with Rician nature of noise present in MR images in Chapter 5. In this, data is first projected to kernel space via function mapping then non local clustering
based denoising framework is adopted in kernel space and inverted back to get denoised MR image.

- Chapter 6 is an extension of methods proposed in Chapter 2 and Chapter 5 from 2D images to 3D volume MR data.

### 7.3 Overall Conclusion

The current work is an early attempt to explore Rough Set Theory for medical image denoising under various frameworks. Starting from filter approaches, more sophisticated and recent mechanism of patch based denoising are attempted. All methods proposed are found to be as efficient as their contemporary methods, if not better. All experiments are performed on phantom datasets; however the same is explored for some real datasets as and when possible.

This work is complete by extending the proposals to denoise the 3D MRI which is gaining lots of attention in recent times. Finally, it is concluded that soft computing approach, specifically Rough Set Theory is successfully applied to MR image denoising and the results are encouraging to researchers for further studies towards possible extensions.

### 7.4 Future Work

The performance comparison of image denoising methods, on Real images like natural or medical, is quite subjective if no gold standard is available. This thesis compares methods on phantom database that is similar to Real human brain MRI scans, some results are also shown on Real MRI data. Brain related diseases such as brain tumor, multiple sclerosis etc. are analyzed based on change in Cerebrospinal Fluid (CSF), Gray Matter (GM) and White Matter (WM) over a period of time. Hence, one needs to keep track of the details of these tissues in MRI scans and hence must be preserved intact during denoising process. This work considers four objects, namely
CSF, GM, WM and rest as Background. Using these four objects/classes, RCL and REM information (Chapter 2) is derived and further used for various denoising frameworks. Methods presented here can be applied to MRI scan of human body such as cardiac, knee by adopting number of objects present in them. Note that one can acquire number of classes according to domain knowledge.

At the end of Chapter 3, a result is presented on brain tumor class estimation. The dice coefficient was found to be 0.71 which is far behind from 1.0 in ideal situation. Hence, one can further take this coefficient values towards unity aiming more feature preservation during denoising. This can also be extendable for identification of other diseases and there by supporting clinical practice and diagnostic.

In Non Local Self Similar (NLSS) framework (Chapter 4), thesis proposes a novel clustering technique based on RCL and REM information between patches. The conventional clustering methods such as K-Means, Finite Mixture Models, segment an image in \( K \) number of clusters if there are \( K \) objects with crisp boundary. The proposed approach assumes rough boundary where overlapping between multiple objects is possible. Hence, method constructs all possible combinations of \( K \) objects as clusters. Clusters, thus formed are not analyzed statistically on the ground of compactness such as mean, standard deviation in the thesis. Such inclusions may enhance the robustness of proposed denoising framework during basis vector formation.

In Chapters 5 and 6, manifold based KPCA denoising framework for Rician noise removal in the 2D and 3D MRI images is presented. During this work, limited subset of kernels having single parameter is experimented. However, this work can further be investigated using various other kernels with a mechanism to adjust kernel parameters. One interesting line of work could be to design a Rician kernel or data adaptive kernel specifically to deal Ricianity conditions. A more analytical study of manifold based methods can be looked upon to investigate behavior of Rician noise under high noisy environment. While performing patch and voxel based denoising, patch and voxel

\(^1\)One can remove skull part in MRI data from some available tools but such methods are outside the scope of the thesis.
are converted to their one dimensional representation which may lose the relation up to some extent. A 2D or 3D PCA/KPCA method can be investigated in the light of preserving structural information in the raw data.