The main conclusions of this research and the scope for further work are presented in this chapter.


6.1 Thesis Highlights

This chapter brings the thesis to a close by presenting the conclusions drawn from the research. The topic of research was introduced in chapter one. A medical perspective of breast cancer was examined in chapter two. A brief overview of fractals was given in chapter three. The two major contributions of the research are presented in chapters four and five. In chapter four, the different methods for estimating fractal dimension and the different features which were derived from these fractal dimensions for the classification of mammograms are detailed. Chapter five is dedicated to the modeling of mammograms using fractal method, for the identification of microcalcifications in mammograms.

6.2 Classification of mammograms by fractal features

Different fractal features derived from fractal dimension were developed, for the classification of mammograms into normal and abnormal. The abnormalities that are considered in this research are masses and microcalcifications. Also these abnormalities can be malignant and benign.

The classification problem was approached initially by considering only the feature, fractal dimension (FD). Differential Box Counting (DBC); Blanket and Triangular Prism Surface Area (TPSA) methods were the different fractal dimension estimation methods used for finding the fractal dimension. It is seen in chapter 4 (section 4.9.2) a classification accuracy of 80.17% was obtained using the TPSA method. Both the blanket and DBC methods gave an accuracy of 6.436% only. The box plots illustrated the overlap of the FD values between the different classes. The Receiver Operating Characteristics (ROC) analysis was done to evaluate the performance of different fractal dimension estimation methods in the categorization of mammograms. Thus, it was evident that even though fractal dimension can represent irregularity of a surface, it cannot completely categorize mammograms into the different classes. Therefore, six fractal features derived from the above three fractal dimension estimation methods, were considered for better classification.
Chapter 6. Conclusions and Future Scope

The fractal feature $f_1$ to $f_5$ are already used in literature for segmentation. The sixth feature $f_6$ was developed during course of this research. The results were analyzed using ROC. The best results were obtained with the feature $f_6$ computed using the Triangular Prism Surface Area method. The table 4.25 gives the number of mammograms which were correctly classified by the feature $f_6$. It is observed that from the total of 799 mammograms, except 11 benign microcalcifications, all the mammograms were correctly classified by this feature $f_6$ obtained using TPSA method. This gave a total classification accuracy of 98.925%. But the same feature obtained by blanket and DBCM gave an accuracy of only 30.413% and 23.905% respectively.

The discriminative nature of the feature $f_6$ was validated by carrying out Statistical Analysis. The performance of the fractal features were compared with the conventional textural features in classifying the mammograms. But, none of the textural features could effectively classify mammograms as efficiently as fractal feature $f_6$. Classification accuracy and Area Under ROC (AUC) are used for comparing of their efficiency.

6.3 Detection of Microcalcifications by fractal modeling

Microcalcifications are of very small size and are camouflaged in the breast tissues making them difficult to detect even by an experienced radiologist. Therefore, in this research, to identify the presence of microcalcifications, mammograms were modeled by fractal modeling technique. The key challenge in any fractal image modeling scheme is the enormous amount of time taken during the encoding process. In conventional fractal modeling method, during encoding, the matching domain is searched for each range by leaving a gap of $R$ or $R/2$ pixels from the present domain. But, as smaller microcalcifications of the size of one pixel will be missed by this procedure, the conventional method was modified by searching the matching domain from the next adjacent pixel itself, of the current domain. This was named as the modified conventional fractal modeling method. This increased the time taken for encoding by a factor of 34.988, but, the microcalcification detection accuracy was
significantly increased from 46% of the conventional method to 82%. The overall detection accuracy (for both normal and mammograms with microcalcifications) for modified fractal modeling was obtained as 88.4035% when compared to the 67% of the conventional fractal modeling method. Since, the time taken for this modified method was very high, different methods were tried to reduce the encoding time.

Instead of searching all the domain blocks, only those domains which have the same properties of mean variance, entropy, mass center and dynamic range need to be searched for a particular range block. The mean variance, entropy and mass center methods reduced the average encoding time to 8.117 minutes, 7.898 minutes and 1.5848 minutes respectively. The shade and non shade method which divided the domains based on dynamic range reduced the time to 0.2937 minutes and also gave the highest microcalcification detection accuracy of 91.542%. This is due to the fact that shade blocks are those blocks which do not have significant variations in the dynamic range of the pixels. Most of the blocks in the mammograms will be shade blocks, as microcalcifications are existing as single or as isolated clusters and are not covering the entire mammogram region. Therefore, the average number of domains to be encoded by fractal method dropped by a factor of 5.143, with respect to the other methods.

Thus, the developed fractal modeling method could effectively detect the presence of microcalcifications in lesser time without compromising the detection accuracy. These results are published in (San 2010).

6.4 Suggestions for Future research

Although the present research gave good results, certain proposals for future work are listed below:

- The key point in the survival of the patient is the stage at which cancer is detected. If sufficient data at different stages of the disease are available, the research can be done for predicting cancer.

- In this research only deterministic properties of fractals were used. Properties like fractional Brownian motion (fBm) may be employed for the
classification and detection. Also, combination of these two can be tried to
further reduce the encoding time and increase the classification accuracy.

- If the encoding time can be further reduced, this method can be utilized for
real time implementation.

- Research may be done to study the shape of the abnormalities present in
mammograms. Fractals provide an excellent means for studying the irregular
geometric patterns.

- During fractal modeling of mammograms; only square blocks were
considered in this research. Adaptive domain sizes may help reducing the
time required for encoding.

- Only spatial domain analysis was done in this research. It may be possible to
obtain better results when other transforms are integrated with fractal
properties.