Chapter 5

Conclusion and future direction

5.1 Concluding remarks

The thesis aimed at developing some robust techniques for effective analysis of HSIs using spectral-spatial information obtained by exploiting mathematical morphology. To achieve the objective of this research, three contributions are presented in the thesis. In this chapter, we summarize each of the contribution along with their limitation and possible future directions.

5.1.1 Contribution 1: Spectral-spatial multi-criteria active learning technique

Spectral-spatial classification of hyperspectral image with limited labeled samples is a challenging task and still an open research issue. In the literature few spectral-spatial AL techniques exist to address such an issue but demands a lot of computational time. As first contribution, in this thesis a novel computationally efficient spectral-spatial multi-criteria active learning technique is presented. The proposed technique is divided into two phases. In Phase I, the dimensionality of the HSI is reduced using PCA and an EMP is constructed to integrate spectral and spatial information of HSI. In Phase II, a multi-criteria batch mode AL technique is proposed by defining a novel query function that incorporate uncertainty, diversity and cluster assumption criteria by exploiting the properties of support vector machines, k-means clustering and K-nearest neighbors algorithm. Finally, GAs are exploited to select batch of most informative samples by optimizing these three criteria. The experiments are carried out on four HSI data sets and from

the experimental results, we observed that the proposed technique consistently provided better stability with high accuracy. Moreover, it is computationally less demanding than the existing spectral-spatial AL technique.

Limitations and possible future developments

(i) The Phase I of the proposed technique integrates spectral and spatial information based on EMP. Attribute profiles are generalization of simple SE based morphological profiles. Consideration of advanced attribute profiles for integrating spectral and spatial information may further improve the performance of the proposed AL technique.

(ii) The proposed technique is based on three different criteria. The technique tries to maximize the uncertainty criterion and minimize the diversity and cluster assumption criteria. As a future development, using a multi-objective optimization technique for optimizing these three criteria may further improve its performance.

5.1.2 Contribution 2: Unsupervised optimal feature selection in EEMAP

In this contribution, a method for improving the classification results of HSI by incorporating spatial information using attribute profiles in its optimal feature space is proposed. For fusing spectral and spatial information, a large EEMAP is constructed for the HSI considering filter parameter values sampled in very small interval from a wide range. Although, the large EEMAP contain variety of spatial information it has very high dimensionality with ample redundancy that increases the computational cost and also may introduce curse of dimensionality problem. To mitigate these problems, the only method exists in the literature that selects subset of features from the constructed EEMAP is supervised in nature and highly computational time demanding. In this contribution, a novel computationally efficient unsupervised feature selection technique is presented that selects an optimal subset of features from the constructed EEMAP for spectral-spatial classification of HSI. The proposed technique first generates a dissimilarity matrix to measure the dissimilarity between each pair of filtered images in EEMAP using MI. Then, to select an optimal subset of features from the EEMAP, GAs are exploited by defining a novel objective function based on the generated dissimilarity matrix. The selected subset of features is considered for classification of the HSI. Exper-

iments on four real HSI data sets demonstrate the effectiveness of the proposed method.

Limitations and possible future developments

(i) In the proposed method the profile is constructed by considering the morphological attribute filters. As a future development of this work other advanced filtering techniques can be explored for constructing spectral-spatial profile.

(ii) Although compared to the existing technique the proposed method reduced the computation time significantly, there is a possibility to further reduce its computational time by parallelizing it.

5.1.3 Contribution 3: Threshold free attribute profiles

The construction of an AP using threshold values (selected manually or automatically) is time-consuming and may result in a large number of features that may introduce *curse of dimensionality* problem. To the best of our knowledge, no method exists in the HSI literature that generates APs without employing threshold values. In this contribution, a novel approach is presented that generates the filtered images for constructing APs without using the threshold values. The proposed approach first creates a tree that represented different connected components of the image, then a novel filtering method is used to detect some nodes on the tree for merging the insignificant objects to their background automatically. The proposed filtering method is repeated to generate multiple filtered images for constructing the APs. Experiments are carried out on four HSI data sets and the proposed method is compared to the recent state-of-the-art method that constructs APs by selecting threshold values automatically. The comparison showed that the proposed method has several advantages: 1) it generates filtered images without using any threshold value; 2) it is fully automatic and independent on the image content; 3) a small number of filtered images generated by this method are capable to capture a large amount of spatial information; 4) it is more robust to avoid curse of dimensionality problem; and 5) it generates the profiles in a much faster way. Moreover, the proposed technique also shows its robustness compared to a large number of spectral-spatial classification techniques existing in the literature.

Limitations and possible future developments

(i) Although, considering different kinds of attributes the proposed method shows significant improvement over the state-of-the-art method. There exists some pure non-increasing attribute like *standard deviation* for which it produces similar classification results as state-of-the-art method. Since *standard deviation* is purely non-increasing in nature, the global maximum in the MSC curve selected by the proposed technique may not be the best one to prune the tree. As a future development the proposed algorithm may be improved to find suitable position in MSC for proper characterization of pure non-increasing attributes.

(ii) The proposed threshold-free attribute filtering technique is well suited for incorporation of proper spatial information for HSI classification. However, it may be applied in different image processing applications where still a threshold based filtering methods are being employed.

5.2 General Limitations and future developments

Following are some possible future developments applicable to all the three contributions.

- *Implementation in parallel processing environment:* Although the proposed approaches significantly reduced the computational time for spectral-spatial classification of HSI, their implementations in parallel processing environment may further reduce the computational time of the proposed methods.
- *Investigating deep learning techniques with mathematical morphology touch:* Although deep learning techniques, especially CNNs are quite successful in HSI classification. Incorporating a morphological filtering capability may further improve its performance. Moreover, construction of threshold-free APs before applying the deep learning methods may further improve the classification performance.