Chapter 6

Conclusions and future scopes

6.1 Concluding remarks

Structure-preserving filters play an important role in many image processing applications. In the last two decades, the developments of filtering techniques has moved from gradient-based edge-preserving filtering to adaptive window-based edge-preserving filtering and region-statistics-based structure-preserving filtering. The concept of structure-preserving filtering is not only to preserve individual edges but also to preserve meaningful objects or structures as a whole while removing insignificant textures. In recent developments, the term semantic-aware structure preserving filtering [145] has been introduced. Defining the semantically meaningful structures of an image is one of the most challenging problems of such filtering. Most of the existing pixel-based or region-based state-of-the-art structure-preserving filtering methods use directional (horizontal and vertical) gradients (or partial derivatives) as structure descriptors, which often fail to preserve the corner edges (i.e., the edges other than horizontal or vertical orientations) properly or often create false edges for different images. They are also prone to removing similar structures (i.e., having similar patterns or statistical features) that are present consecutively. To get the best results from these methods, a huge amount of empirical study is needed by manually defining the neighbor window size, the region window size, or the parameters of kernel functions. Morphological filters are able to preserve the structure of the objects without using statistical measures, but it heavily depends on the size and shape of the structuring element. In the literature, some recent methods have used adaptive structuring elements for structure-preserving filtering by taking a threshold in bilateral function. Connected component filtering is an advanced version of morphological filtering that can also be applied to preserve the structure of the objects in the image, but it depends on the component ordering and the considered threshold value. Thus, only morphological or connected component filters are not robust enough to develop semantic-aware structure-preserving filters. In the context of current literature, a lot of research is going on towards the development of robust semantic-aware structure-preserving filtering, but no standard generalized technique has yet been developed. In this thesis, we have exploited and combined the properties of both statistical region-based properties with morphological and adaptive median filtering to develop a few robust semantic-aware structure-preserving filters. Finally, we have applied and tested them for effective classification of remote sensing images.

The main challenge for developing a robust structure preserving filtering technique lies in the fact of handling varying scale textural patterns. In order to better handle varying scale textural patterns, in the first contribution we have proposed a semantic-aware structure preserving adaptive median morpho-filtering technique. Our technique defines a novel method to obtain an edge-aware adaptive window of dynamic shape for filtering each pixel by excluding its neighbour pixels belonging to different textural or structural regions. To this end, at first, a novel approach is proposed to generate the edge-map by analysing the skewness of global and local histograms of the morphological gradient. Then, using the generated edge-map a semantic-aware structure preserving adaptive median morpho-filtering is designed by combining the output of median and morphological filters. The major contributions of this research are: i) proposes a texture structure decomposition technique analysing the global and local morphological gradient distribution, and ii) proposes a combined median morpho-filtering for better texture smoothing while preserving the significant structures. Unlike most of the existing techniques, our filtering can achieve multiple conflicting goals, like protecting structural edges, safeguarding easy-to-miss features such as corners, and Inhibiting over-sharpening and/or over-blurring artifacts/distortions while identifying and removing texture.

Structural edge-aware features are more resilient than textural features for filtering images with varying scales of irregular textures. However, the effectiveness of edge-aware filtering techniques is dependent on their ability to identify the right structural edges. In the second contribution to the thesis, we propose a novel and different approach for structural edge pattern detection than the previous one. It explores Jensen Shannon divergence (JSD) metric to identify the structural edge pattern of the image by considering the semantic information of the image. In this technique, structural edge pattern is defined by exploiting Jensen-Shannon (JS) divergence as a similarity /dissimilarity metric between the approximated real edge and ideal edge or non-edge pattern (step or uniform) in such a way that they incorporate semantic information of the pixel for determining whether it is a structural edge pixel or not. We proposed two different approaches to use this. In the first approach, we directly compared the metric for step and uniform pattern to get the edge-map. Whereas in the second approach, a set of novel features is proposed to represent the pixels of the input image. These features are generated by combining JSD metric and Gaussian mean difference using sigmoid function to generate semantic features of the pixels. By projecting the pixels into the feature space, our technique applied k-means clustering to generate a semantic-aware edge-map of the input image. Once the edge-map is obtained, an edge-aware adaptive recursive median filter is applied to generate the filtered image. Unlike the existing state-of-the-art techniques, the proposed technique reduced the parameter sensitivity and requires minimal manual fine-tuning of its parameters to get best possible results for different input images.

In the third contribution, we propose a novel method that leverages the semantic information of the image to enhance the discrimination between structural and textural edges by combining both the techniques introduced in first and second contribution. Our technique initiates by generating a semantic-aware edge-map through the exploitation of semantic information in two phases. In the first phase, it explores local morphological gradients skewness and mean difference gradient both as semantic feature for initial texture structure decomposition and generate a semantic gradient image (SGI). Then the second phase it uses this SGI to determine the window sizes of each pixels by categorizing pixels into four parts. The second and final layer of texture structure feature generation use JS divergence metric based structural edge pattern detection in the same way as in the first approach of second contribution. This final layer of feature decomposition generates the semantic-aware edge-map. Subsequently, an edge-aware adaptive recursive median filter is utilized to produce the filtered image using this edge map. Although our filtering technique requires defining multiple windows, the sizes and shapes of most of these windows are either automatically determined or remain fixed regardless of the input images under consideration. Only a pair of windows necessitate manual fixing by selecting one of four discrete options. This proposed parameter efficient technique yields satisfactory results across a diverse range of input images with minimal parameter fine-tuning, presenting a significant advantage over current state-of-the-art techniques.

To emphasize the validation of effectiveness through comparative analysis of all the proposed techniques with several state-of-the-art techniques employing a wide variety of images consisting of varying scales of regular and irregular textures. It also applied effectively to few computer graphics applications like image denoising, image enhancement, tone mapping *etc.* These proposed techniques can achieve several competing objectives that cannot be accomplished by using a single existing method, such as detecting and smoothing textures, protecting corners and other areas that are easy to overlook, avoiding over-blurring and/or over-sharpening artifacts, and maintaining structural edges. Although all our developed technique successfully works on a variety of images but our present implementation is not of real-time. Implementation of our technique in real-time or near real-time and apply this technique to different image/video processing applications like semantic segmentation, object detection and classification etc would represent an intriguing continuation of this research.

Hence, in the fourth and final contribution we have tested the above presented different semantic filtering based feature extraction in HSI classification. Semantic-aware image filtering techniques discussed in chapter 2, 3, 4 preserve the structures of the objects while removing insignificant textures and noises from the image by considering semantic information. Although filtered images generated by such advanced techniques provide better spatial information, they are seldom exploited for HSI classification. In the fourth and final contribution of this research, we have exploited all the above proposed semantic-aware filtering technique to generate the filtered images of HSI. Then an extended semantic filtering profile (ESFP) is constructed by concatenating the generated filtered images for spectral-spatial classification of HSI. Then the generated ESFP is fed to a random forest (RF) classifier for classifications of land covers of three well established HSI datasets. The effectiveness of the proposed technique has been validated by comparing it with that of many state-of-the-art spectral-spatial HSI classification techniques which incorporate spatial information by exploiting MRF, MM, segmentation, sparse representation, or deep neural networks. The results of the comparison pointed out the superiority of the semantic filtering technique. In the future, this research could explore to use ESFP as an input to the deep models for extracting better features.

Traditional image filtering approaches are usually faster in inference, as they lack the depth and iterative processes of deep learning or sparse optimization. This speed can be a significant advantage for real-time or near real-time applications, where rapid processing is essential. For deep learning architectures, inference may be slower, especially on hardware without dedicated accelerators (e.g., GPUs or TPUs). Sparse approaches, with their iterative nature, may also have slower inference times due to the convergence checks in each step. While deep learning methods often have lengthy training times. Our developed filtering based approaches generally do not require training (or have very minimal requirements if used within a semi-supervised or unsupervised framework). Sparse methods may involve training but usually involve fewer iterations or layers than deep networks. So the proposed filtering techniques applied to hyperspectral image classifications are computationally much more effective than the existing deep learning or sparse representation based approaches.

6.2 Future scopes

We believe that such developments will have a great impact on other diverse image processing applications too. The future developments of the present work will be in three different directions: one is the real-time/faster implementation of the developed techniques; the second is to explore such techniques in other image and video processing (like real-time semantic segmentation, classification) applications like medical image analysis, text image analysis, *etc*, and the third is to model a robust deep neural network leveraging the proposed semantic features.