Abstract

Image filtering techniques play a crucial role in enhancing the quality of images. Digital images acquired by sensors often suffer from geometric, radiometric, and sensor-related distortions and noises. These imperfections can degrade image quality substantially. In turn, the effectiveness of image processing and analysis methods is closely tied to the quality of input images. Consequently, image filtering has become an essential and indispensable step in many image processing and image analysis applications.

There exist two approaches: spatial and frequency domain image filtering. Spatial domain filtering is inherently intuitive as it directly operates on image pixels, whereas frequency domain filtering works on signals derived from digital images. The spatial domain offers a practical advantage in image processing by enabling direct pixel-based operations, which preserve structures and enhance specific regions without the artifacts that can arise from frequency domain transformations. This approach is computationally simpler, supporting real-time applications that require fast processing. Additionally, it allows for flexible integration of semantic information, such as edges and textures, which are critical for tasks like object detection, segmentation, and classification, where maintaining spatial details is essential. Overall, the spatial domain is ideal for applications where clarity, precision, and efficiency are prioritized. Spatial domain image filtering techniques have evolved from basic linear filters to advanced non-linear ones, including edge-preserving filters, adaptive filters, region-based structure-preserving filters, and morphological filters. Over the past two decades, there has been a shift from gradient-based edge-preserving filtering to adaptive window-based edge preserva-

tion and region statistics-based structure preservation. These structure-preserving filtering techniques aim not only to preserve individual edges but also to retain meaningful structures while eliminating insignificant ones.

The gradual developments of pixel-based filtering methods primarily rely on region-based directional gradients (horizontal and vertical) and statistical measures, such as total variation (TV), relative total variance (RTV), and region covariance, as descriptors of structures and textures. These methods often struggle to effectively preserve the edges of objects and perform poor smoothing for varying scale textures/noises. Also, achieving optimal results with these approaches requires meticulous parameter tuning, involving the selection of appropriate neighbor window, region window, or kernel functions.

In recent times, the concept of semantic-aware structure-preserving filtering has emerged. Defining semantically meaningful structures within an image is one of the most challenging aspects of developing such filtering techniques. To address these challenges, in this thesis, we have proposed and developed a few robust semantic-aware structure-preserving filtering techniques. The basic approach of these techniques begins by generating a semantic-aware edge map that leverages the semantic information from the input image. Using this edge map, an edge-aware adaptive filtering technique is then developed.

As a first contribution of this thesis, a novel semantic-aware adaptive median morpho-filtering technique is proposed. First, it generates an edge-map by using semantic information extracted from the global and local morphological gradient histograms obtained from the input image. Then, using the generated edge-map a novel adaptive median morpho-filtering technique is proposed by defining a dynamic window that avoids overlapping of textural and structural contents of the image. Although the proposed technique provides satisfactory results for wide varieties of input images, the size of the window taken for considering semantic information is a critical parameter of this technique. The filtering result is significantly dependent on this parameter.

In order to reduce the limitation of the above filtering technique, in the second contribution, a completely different approach is proposed to generate the semantic edge-map of the input image. We exploit Jensen-Shannon Divergence (JSD) to incorporate semantic information into edge-map generation. Here, we present two approaches for generating semantic edge-maps using JSD. In the first approach, JSD is directly used to distinguish between structural edge pixels and non-edge pixels. Where as in the second approach, a set of novel features are proposed to represent the pixels of the input image. These features are defined by exploiting Jensen-Shannon (JS) divergence in such a way that it incorporates semantic information of the pixel for determining whether it is a structural edge pixel or not. Then, projecting all the pixels into the feature space, a semantic-aware edge-map of the input image is generated by applying k-means clustering. Once the edge-map is obtained, the edge-aware adaptive recursive median filter proposed in the first contribution is used to generate the filtered image. Compared to the existing state-of-the-art methods, the proposed method outperforms for a wide variety of images with the minimal fine tuning of its parameters within a few discrete options.

The third contribution of this thesis introduces a parameter-efficient filtering technique that builds on the semantic information developed in the first and second contributions. This novel approach generates a semantic edge map of the input image by leveraging the morphological gradient distribution from the first contribution and the Jensen-Shannon divergence introduced in the second. Once the edge map is constructed, the edge-aware adaptive recursive median filter, also presented in the first contribution, is applied to produce the filtered image. Notably, this technique requires only one parameter, manually defined within four discrete options, making it efficient and straightforward to use. The effectiveness of the proposed method has been validated across a wide range of input images.

While image filtering techniques are widely employed in various computer graphics applications, they are rarely leveraged to incorporate spatial information for image classification tasks. The fourth key contribution of this thesis addresses this gap by demonstrating the effectiveness of our proposed filtering techniques

in enhancing hyperspectral image (HSI) classification through spatial information incorporation. Our filtering techniques are designed to preserve object structures effectively while reducing noise and texture, thus enabling the filtered images to retain valuable spatial information.

In this contribution, we first apply one of our proposed filtering techniques to generate multiple filtered versions of the HSI, creating a filtered profile. This profile provides spectral-spatial features for each pixel, which are then used as input to a classifier for HSI classification. The effectiveness of our approach is validated by comparing it to several leading spectral-spatial HSI classification methods.

Finally, we draw conclusions and discuss potential future advancements to extend this work further.

Keywords: Image filtering, edge-aware filtering, structure-preserving filtering, texture filtering, structure texture decomposition, semantic-aware image filtering, semantic image filtering