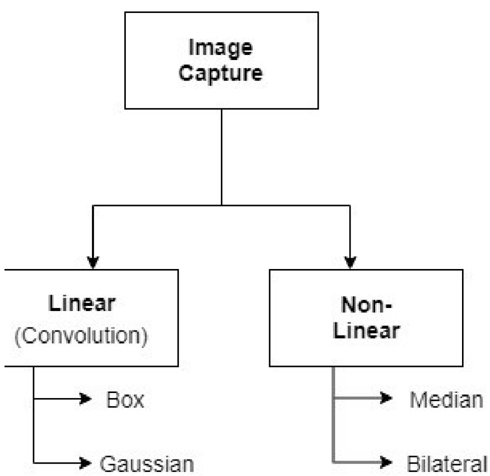
Study on Image Filtering

A Preprint

This paper introduces various image filtering techniques and their wide applications.

Most of algorithms may be described by dividing into two different types: linear and non-linear. While linear filter can be achieved using conv or Fourier, non-linear can t. Median filter is the most effective non-linear filter if coming to salt and paper noise(random dots, noisy, e.t.c). This filter basically retains edges and removing noise. As for Bilateral filter, it reduces noise by smoothing and also preserves edges. It takes weighted sum of the pixels which are close to each other and replaces intensity with average of this weighted sum.



In box blur (or so called mean filter) for each pixel 3x3(actually k x k but here it is taken just for example) region is taken. Mean is calculated throughout this region nad origin pixel is repplaced. A Gaussian filter is a more advanced and effective way to smooth or blur an image compared to a box blur. It also uses a neighborhood of pixels (e.g., 3×3, 5×5, etc.), but instead of giving equal weight to all pixels, it applies a Gaussian-shaped weighting, basically giving more weight to the center pixel and less to those farther away. next assumptions for detecting noise are made:

- i) in an image which is noise-free edges separate the smoothly varying areas
- ii) the pixel which is noisy in the image has uneven intensity i.e. either very low or very high in comparison of the neighborhood pixels

Median filter

Noise detection procedure(nessecary for saving edges, details and so on):

Algorithm 1 Algorithm

Require: Image

1: Assume a window (2W+1)x(2W+1) ▷ $W \geq 1$

2: Finding windows, median value $m_{(n-1)}^{(i,j)}$

3: The absolute difference between $x_{i,j}^{(n-1)}$ and $m_{i,j}^{(n-1)}$ is used to update the noise flag $f_{i,j}^{(n)}$:

$$f_{i,j}^{(n)} = \begin{cases} f_{i,j}^{(n-1)}, & \text{if } \left| x_{i,j}^{(n-1)} - m_{i,j}^{(n-1)} \right| < T_1 \\ \text{noise}, & \text{otherwise} \end{cases}$$

4: If noise is detected at pixel (i, j), then the value $x_{i,j}^{(n)}$ is updated as:

$$x_{i,j}^{(n)} = \begin{cases} m_{i,j}^{(n-1)}, & \text{if } f_{i,j}^{(n)} \neq f_{i,j}^{(n-1)} \quad \text{(i.e., noise detected)} \\ x_{i,j}^{(n-1)}, & \text{otherwise} \end{cases}$$

Gaussian blur also can be interpreted as diffusion, equally distributing values of intensity. The bilateral filter, unlike Gaussian blur, delivers sharper and superior results by focusing on maintaining the object outlines. It has many applications in fields like movie restoration and medical imaging.

1 Applications of Image Filtering

Image filtering is widely used to enhance image quality by modifying pixel values through blurring, smoothing, and sharpening. Filters operate on all image types and are applied via raster/vector tools or 3D modeling software.

Denoising: Bilateral filtering combines spatial and range weights, preserving object boundaries while effectively removing noise, unlike Gaussian blur which smooths uniformly.

Compression: Lossless compression is preferred in technical domains like medical imaging or clipart. Lossy compression may introduce artifacts but can be visually acceptable at moderate bitrates.

Texture–Illumination Separation: Bilateral filters help separate lighting variations from texture, useful in image-based modeling by preserving geometric and brightness discontinuities.

Character Recognition: Optical character recognition (OCR) converts printed text into digital form for editing, search, and storage. Modern techniques can handle layout structures and unprinted content.

Signature Verification: Digital signature systems ensure authenticity, integrity, and non-repudiation in electronic communication and are used in software distribution and legal communication.

Biometrics: Filtering supports biometric systems like fingerprint verification. Benchmarking tasks involve evaluating recognition accuracy using standard datasets and sensor conditions.

Object Recognition: Identifies semantic objects (e.g., people, cars) in images or video, with applications in face detection, surveillance, and retrieval.

Face Detection: Detects human faces by locating their position and scale in images, forming the basis for higher-level recognition systems.

Medical Imaging: Filtering is integral to modalities such as X-ray, MRI, ultrasound, and PET. It enhances diagnostic clarity by reducing noise and improving contrast.

2 Conclusion

Image filtering plays a central role in image processing tasks such as enhancement, denoising, edge detection, and compression. Filters operate via local kernels applied across pixel neighborhoods. Median and bilateral filters are effective in noise reduction while preserving edges. Gaussian filters offer computational efficiency with less edge preservation. Box filters are suitable when noise reduction is the only concern. For practical purposes, a kernel size of 7 or less is recommended to balance quality and performance.