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The use of Different Filters and their effects on Convolution with Grayscale Images

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Abstract: Computer vision is ubiquitous in the world today, starting from unlocking phones to robots performing complex surgeries in hospitals and managing the assembly line in factories. In this paper, the focus has been placed on the use of filters or kernels or masks and their effects when convolved with grayscale images.

Keywords: Computer Vision, Filters, Convolution, Fuzzy-Filters, Noise, Gaussian

I. INTRODUCTION

When we capture an image with our smartphone camera, or with our DSLR, we do not always get the raw image in the form that we desire. Some images may be too sharp, some may be too noisy. In some cases, we significantly need to alter the colors to get the photo we desire. In this paper, some of the steps and procedures used to smoothen images and remove unwanted noise from pictures has been considered for discussion.

II. CONVOLUTION (1D) - SIGNALS

A. Linear Shift Invariant Systems (LSIS)

As is clear from the name, each LSIS system must be Linear in nature and be shift invariant. Let g be obtained after LSIS on f . That is, to say that $f(x) \xrightarrow{LSIS} g(x)$. Then, if

$$f_1(x) \xrightarrow{LSIS} g_1(x) \text{ and } f_2(x) \xrightarrow{LSIS} g_2(x) \quad (1)$$

and $\alpha, \beta \in R$, then

$$\alpha f_1(x) + \beta f_2(x) \xrightarrow{LSIS} \alpha g_1(x) + \beta g_2(x) \quad (2)$$

The property in (2) is called the Linearity Property. Another property that LSIS satisfies is that

$$f(x - a) \xrightarrow{LSIS} g(x - a) \quad (3)$$

The property in (3) is called the Shift Invariant Property. It can be shown that Convolution \Leftrightarrow LSIS

B. Convolution

The convolution of two functions $f(x)$ and $h(x)$, denoted by $*$ is defined to be

$$g(x) = f(x) * h(x) = \int_{-\infty}^{\infty} f(\tau)h(x - \tau)d \quad (4)$$

Let us consider two functions $f_1(x)$ and $f_2(x)$ and convolve them with a function $h(x)$.

Then, $g_1(x) = \int_{-\infty}^{\infty} f_1(\tau)h(x - \tau)d \tau$ and $g_2(x) = \int_{-\infty}^{\infty} f_2(\tau)h(x - \tau)d\tau$. Now, if we consider the function $\alpha f_1 + \beta f_2$, then,

$$\begin{aligned} G(x) &= \int_{-\infty}^{\infty} (\alpha f_1(\tau) + \beta f_2(\tau))h(x - \tau)d \tau \\ \Rightarrow G(x) &= \alpha \int_{-\infty}^{\infty} f_1(\tau)h(x - \tau)d\tau + \beta \int_{-\infty}^{\infty} f_2(\tau)h(x - \tau)d \tau \\ \Rightarrow G(x) &= \alpha g_1(x) + \beta g_2(x) \end{aligned} \quad (5)$$

Equation (5) shows that the Convolution operation $*$ is Linear in nature. Now, to show shift invariance, let us consider

$$g(x) = \int_{-\infty}^{\infty} f(\tau)h(x - \tau)d \tau$$

Then,

$$\begin{aligned} \int_{-\infty}^{\infty} f(\tau - a)g(x - \tau)d \tau &= \int_{-\infty}^{\infty} f(\mu)g(x - a - \mu)d \mu \quad (\text{Putting } \mu = \tau - a) \\ &= \int_{-\infty}^{\infty} f(\mu)g(x - a - \mu)d \mu = g(x - a) \end{aligned} \quad (6)$$

V. BLOCK FILTER

A block filter is used to blur or smoothen images. In such a filter, each element of the kernel is either 1, or is normalized by the sum

of all entries, i.e., $\frac{1}{k^2}$ for a k -dimensional filter. A 3-dimensional block filter is $\begin{bmatrix} \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \end{bmatrix}$.

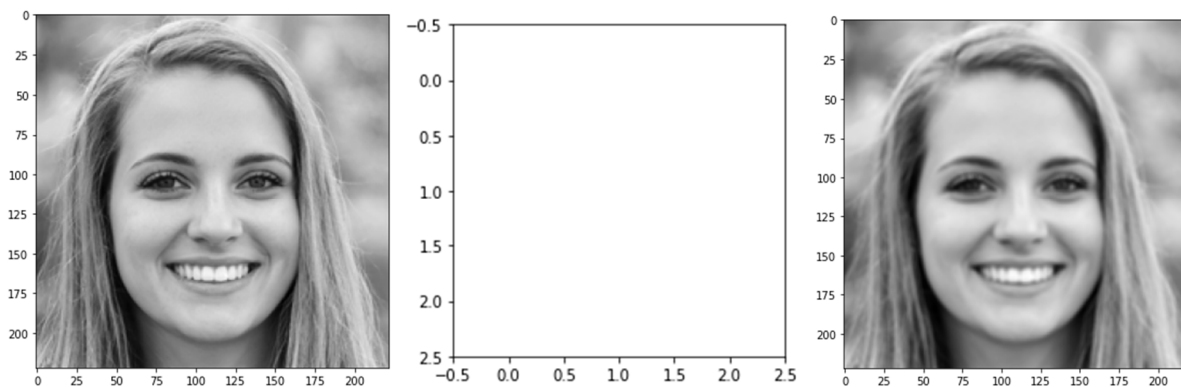


Fig. 3 (a) Original 224×224 Image (b) Kernel of size 3 with all elements $\frac{1}{9}$ (c) Smoothed Image after convolution with kernel

Notice that the blurring effect is not that visible, but it is certain that the image on the right has much smoother boundaries than the image on the left. Let us increase the filter size to 4 and 10 respectively in Fig. 4 and Fig. 5 to see the changes.

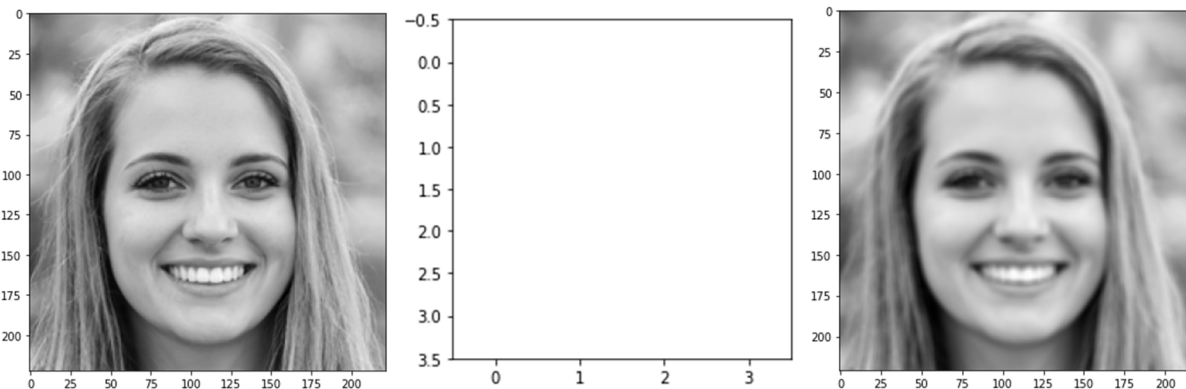


Fig. 4 (a) Original 224×224 image (b) Kernel of size 4 with all elements $\frac{1}{16}$ (c) Smoothed image after convolution with kernel

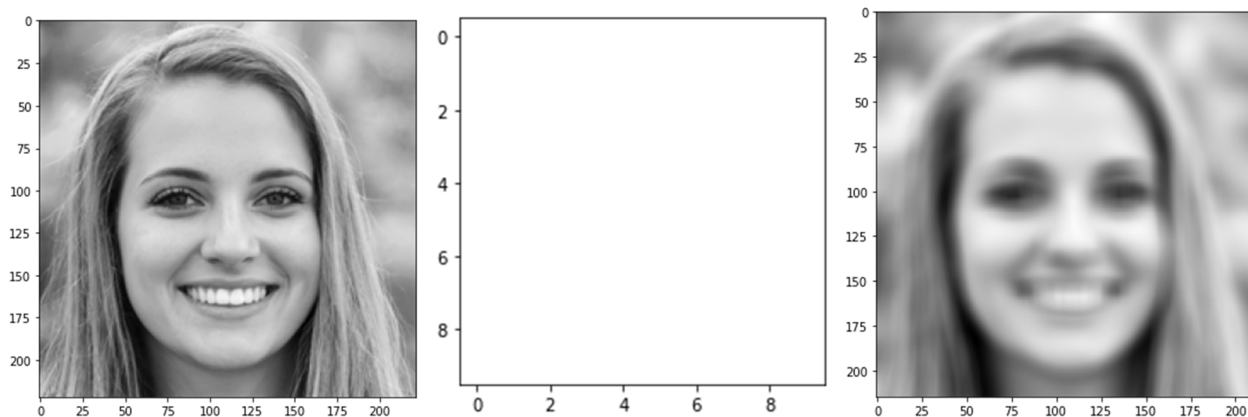


Fig. 5 (a) Original 224×224 image (b) Kernel of size 10 with all elements $\frac{1}{100}$ (c) Smoothed image after convolution with kernel

Dividing by the sum of all elements is just a normalization procedure to prevent over-saturation. If all elements had been 1, after convolution, each pixel would have contained a very high value and the image would have appeared washed out. Now, notice that as we smoothen the images, there are some square patterns that appear throughout the image, especially observable in Fig. 5 (c). That is because we have applied a block filter, and its block characteristic has been made prominent throughout the image. To avoid this, we use a Fuzzy Filter.

VI. FUZZY FILTER

A fuzzy filter is used to prevent the appearance of block like features that arise upon convolving with a block filter. In a fuzzy filter, the value at the centre is maximum, and they decrease as we move towards the edges and corners. A fuzzy filter is rotationally symmetric. A very good example of a Fuzzy Filter would be the Gaussian Kernel, n_σ . Each element of n_σ is given by

$$n_\sigma[i, j] = \frac{1}{2\pi\sigma^2} e^{-\frac{i^2+j^2}{2\sigma^2}} \quad (8)$$

The larger the value of σ , the broader or more spread is the filter. For a given σ , it is a common and good practice to choose $k \approx 2\pi\sigma$, where k is the size of the kernel. The larger the value of sigma, the greater will be the blurring effect.

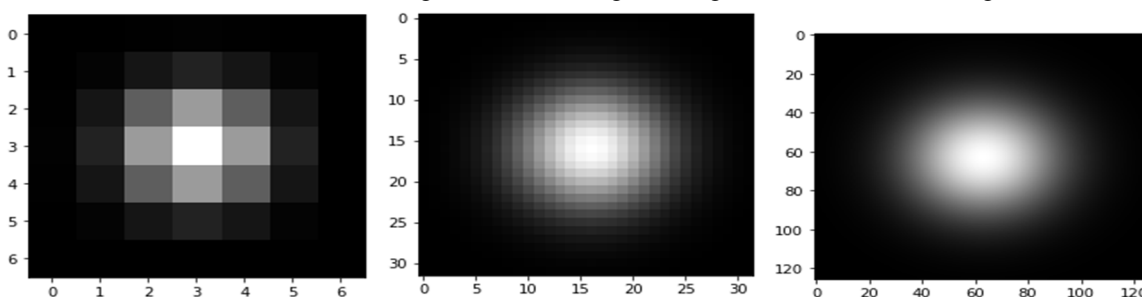


Fig. 6 Gaussian Kernels (a) $\sigma = 1$ (b) $\sigma = 5$ (c) $\sigma = 20$

Some results of convolution with Fuzzy (Gaussian) Kernels are given in the following figures.

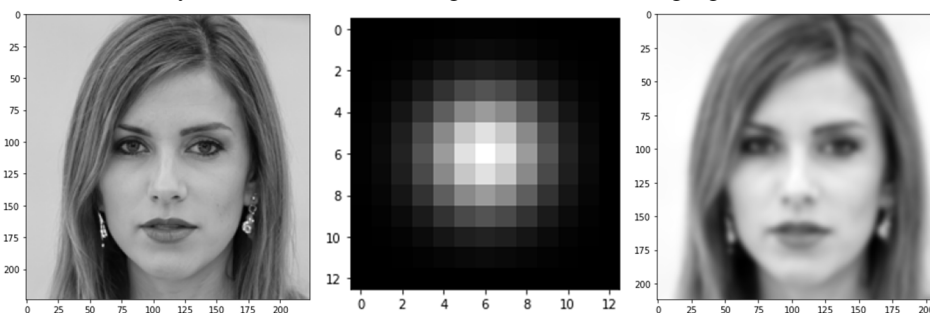


Fig. 7 (a) Original 224 × 224 Image (b) Gaussian Kernel of size 13 (c) Smoothed Image after convolution

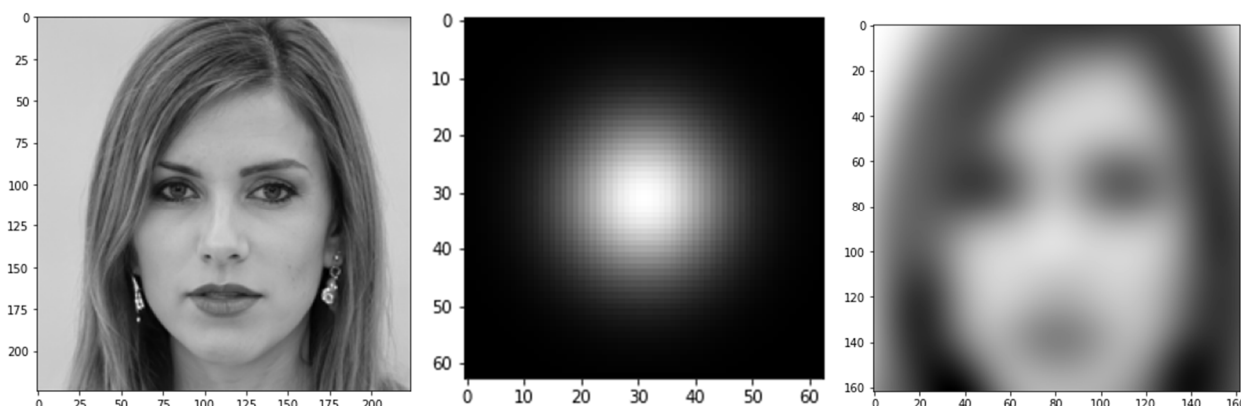


Fig. 8 (a) Original 224 × 224 image (b) Gaussian Kernel of size 63 (c) Smoothed Image after convolution

VII. UNI-CRISP FILTER AND SOBEL FILTER

Uni-crisp filter and Sobel filter are used to detect edges in an image, or in other words, sharpen an image. The Uni-crisp filter is

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix} \text{ and the Sobel filter is } \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}. \text{ The results of convolution are as follows:}$$

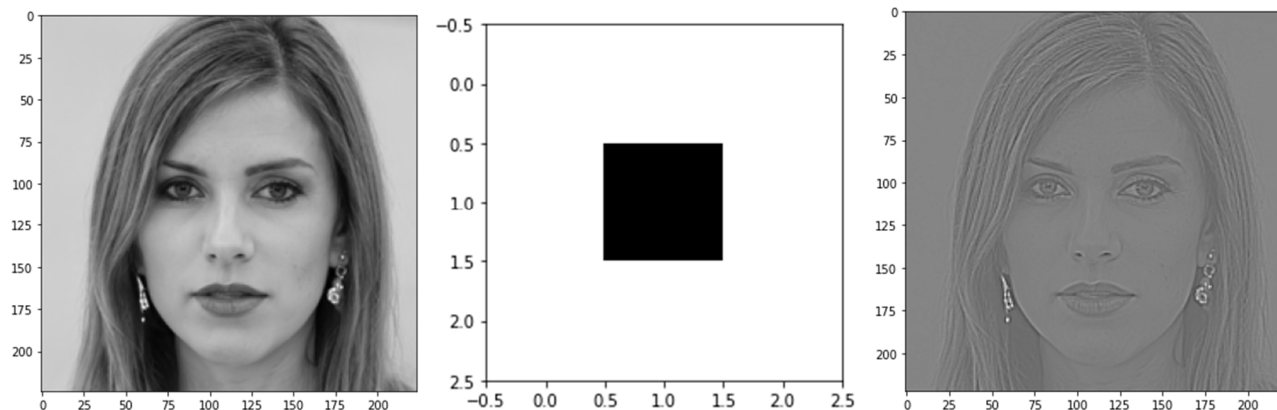


Fig. 9 (a) Original 224 × 224 Image (b) Uni-crisp Filter (c) Sharpened Image after convolution with Uni-crisp Filter

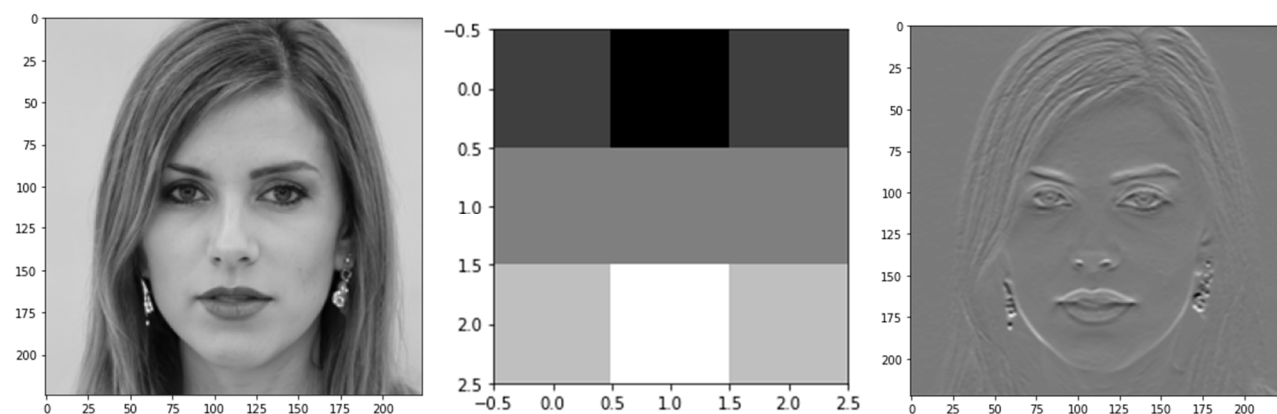


Fig. 10 (a) Original 224 × 224 Image (b) Sobel Filter (c) Sharpened Image after convolution with Sobel Filter

VIII. SALT-PEPPER NOISE AND MEDIAN FILTERING

Noise means random disturbance in a signal in a computer version. In our case, the signal is an image. Random disturbance in the brightness and colour of an image is called Image noise. As the name suggests, salt-pepper noise are random white dots in dark regions and black dots in light regions. This type of noise is found only in grayscale images.

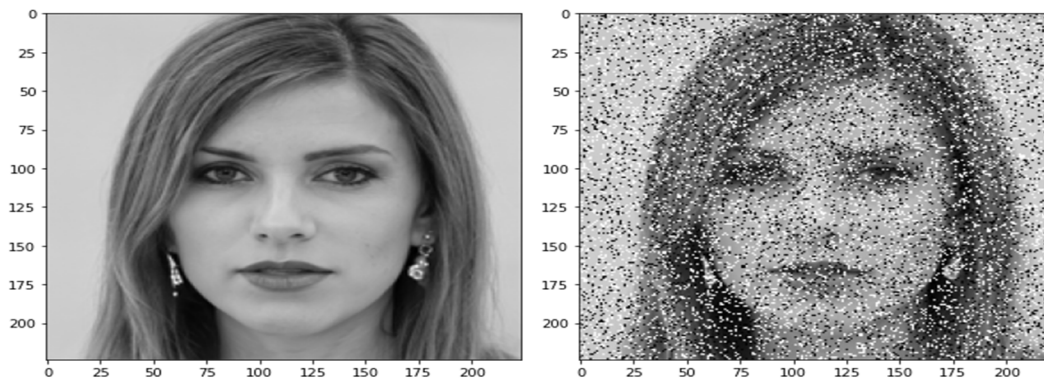


Fig. 11 (a) Original Image (b) Image with Salt-Pepper Noise

A common way to filter out the salt-pepper noise is to use the median filter. To create a median filter, place the $k \times k$ kernel as required during the above-mentioned convolution process. Sort the k^2 values in ascending order and assign the middle-most value to the pixel at the centre. It is important to note that the median filter is not a linear, or for that matter LSIS filter and hence, cannot be applied through the usual convolution process. It needs to be applied through the ordinary raster-scan process.

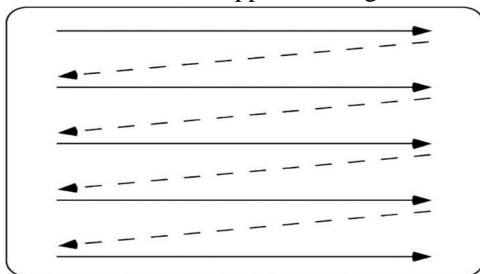


Fig. 12 Raster Scan

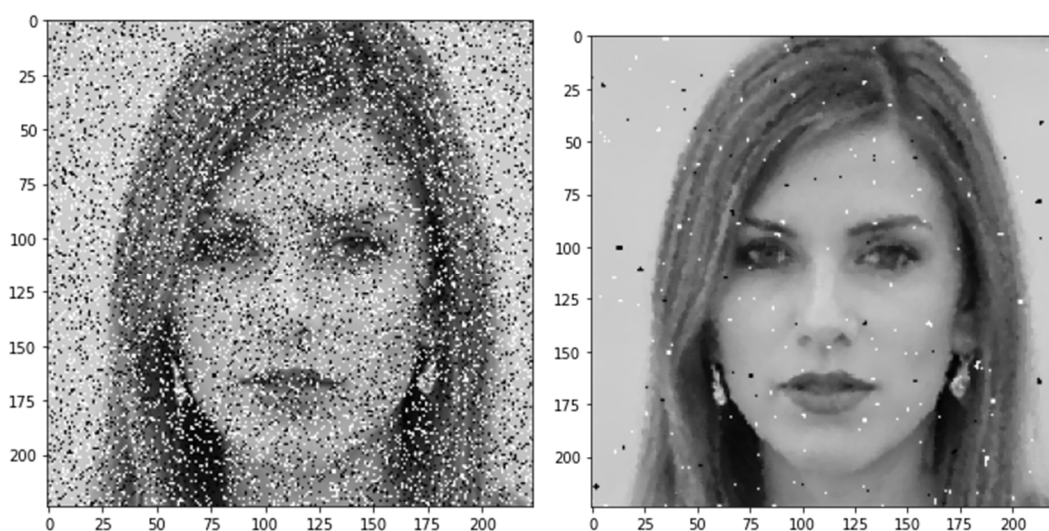


Fig. 13 (a) Image with Salt and Pepper Noise (b) Image filtered, using the Median Filter

IX. CONCLUSION

These are some of the crude techniques employed in computer vision. Of course, when you turn on the filtering option on your smartphone cameras, or the night-mode on your smartphone captures superb images even in extremely low-light conditions, there are much more sophisticated algorithms at work. But, all sophisticated algorithms at play in modern day devices stem from these algorithms, which make their study even more worthwhile.

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