Fourier Transform and Frequency Filtering

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# Introduction

# This document is the report of my Assignment 2 from my Fall 2023 class CAP-5400 Digital Image Processing, as a graduate student. The individuals who are overviewing this assignment are our professor Dr. Dmitry Goldgof and Mr. Anthony McCofie (Teaching Assistant). The purpose of this algorithm is to discrete Fourier transform in grey-level images along with High/low filter cut-off frequency. Additionally

# Discrete Fourier Transform

The Discrete Fourier Transform (DFT) is applied to grayscale images to convert them from the spatial domain to the frequency domain. This transformation allows for various image processing tasks. It can help analyze the frequency components within the image, useful for tasks such as image compression, image enhancement, filtering, denoising, and feature extraction. DFT enables the manipulation and extraction of specific features and patterns in the image, making it valuable for a wide range of applications in image processing and computer vision, including image compression, noise reduction, and feature extraction.

## Implementation

To process an image using the Discrete Fourier Transform (DFT), follow these steps: First, resize the image to an optimal size, ensuring it's a multiple of two, three, or five for improved DFT performance. Then, allocate space for both complex and real values by converting the image to a float format with an extra channel for complex values. Apply the DFT, calculate the magnitude of the complex results, and convert to a logarithmic scale for visualization. Next, crop the image and rearrange quadrants for visualization purposes, and finally, normalize the values to the range of zero to one using `normalize()` for proper display, facilitating the visualization of frequency components in the image.

 A light shining in the sky

Description automatically generated

**Figure 1: Left image - Original image, Right image – Fourier Transform**

## Low-pass Filter

Using a lowpass filter in Fourier transform involves attenuating high-frequency components while preserving low-frequency ones. A low-pass filter applied to an image in the frequency domain smooths or blurs the image, reduces noise, and softens sharp edges. This leads to a cleaner appearance but can also result in a loss of fine details and reduced image contrast.

A math equation with black text

Description automatically generated

**Figure 2: Low Pass Filter equation**

* **H(u, v) is the filter on the frequency domain.**
* **M and N are the number of rows and columns of the filter**
* **The sqrt expression represents the circular shape of the filter**
* **F cut off frequency.**

**A close-up of a person

Description automatically generated** **A person wearing a hat

Description automatically generated**

**Figure 3: Inverse Fourier Transform with a Low Pass Filter (F = 20 & 50)**

## High-pass Filter

Applying a highpass filter in Fourier transform entails emphasizing high-frequency components while suppressing low-frequency ones. In the frequency domain, a high-pass filter enhances image details, highlights edges, and accentuates fine features, resulting in increased image contrast. However, this process can also introduce noise and may make the image appear sharper and less smooth, potentially leading to some visual artifacts and reduced overall image smoothness.

A person wearing a hat

Description automatically generated A person wearing a hat

Description automatically generated

**Figure 4: Inverse Fourier Transform with a High Pass Filter (F = 15 & 20)**

A square root of a mathematical equation

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**Figure 5: High Pass Filter equation**

## Band-pass Filter

A bandstop filter is typically used to remove interference or unwanted frequencies from an image. When applied to an image in the frequency domain, it selectively eliminates a narrow band of frequencies, effectively removing specific patterns or noise. This process can help in isolating or extracting certain features or regions of interest while filtering out undesired components. To implement this filter just take the difference between the High and Low pass filters. Just make sure the cutoff for the High filter is lager than the Low filter.

A large building with many spires

Description automatically generated

**Figure 7: Cathedral Gray-Scale Image**

A close-up of a building

Description automatically generated A greyscale shot of a building

Description automatically generated

**Figure 8: Left – Low Pass (F=20), Right – High Pass (F=50)**

A large building with many towers

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**Figure 9: Band Stop Filter Image (Low=20, High=50)**

## Unsharp Masking

Unsharp masking is an image enhancement technique that involves creating a "mask" image by subtracting a blurred version of the original image from the original. This mask is then amplified and added back to the original image to enhance its sharpness and fine details, making edges and features stand out more clearly. To compute it, just filter out an image (I used a gaussian filter, but can be done with a high pass filter) and get the difference with the original. Then multiply the frequency domain with T, after that add the filter.

A math equations with black text

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**Figure 10: Unsharp Masking equation**

A large building with many windows

Description automatically generated

**Figure 11: Left side – Unsharp Masking (T=50), Right side - Original image**

# Conclusion

In conclusion, histogram stretching is a valuable image enhancement technique used to improve the contrast and visibility of image details. However, when it comes to preserving natural color balance and achieving better control over contrast enhancement, histogram equalization in the HSI (Hue, Saturation, Intensity) color space often outperforms its counterpart in RGB (Red, Green, Blue). By separating the luminance (intensity) from the color information, HSI-based equalization allows for precise control, preventing unnatural color shifts and maintaining the image's overall visual appeal. This makes HSI-based histogram equalization a preferred choice for various image processing tasks where color fidelity and natural appearance are essential.