



DEPARTMENT OF COMPUTER SCIENCE

IT3212 - DATA-DRIVEN SOFTWARE

Assignment 2

Authors:

Birk Strand Bjørnaa
Carl Edward Storlien
Christian Stensøe
Åsmund Løvoll

Table of Contents

List of Figures	ii
List of Tables	ii
1 Changelog	1
2 Fourier Transform	2
2.1 Frequency Spectrum	2
2.2 Low-Pass Filter	3
2.3 High-Pass Filter	7
2.4 Image Compression with Fourier Transform	10
2.4.1 Advantages of Image Compression with Fourier Transform	11
3 PCA	13
3.1 Reconstruction of Images	13
3.2 Experimentation	13
3.3 Visual Analysis	14
3.4 Error Analysis	15
4 HOG features	16
4.1 Figures and results	16
4.2 Parameters discussion	17
5 Local Binary Patterns	18
5.1 Images used and method	18
5.2 Histograms and discussion	18
6 Blob Detection	20
6.1 Parameters discussion	20
6.2 Conclusion	20
7 Contour Detection	22
7.1 Advantages and Limitations	22
7.2 Parameters discussion	22
7.3 Visual representation and conclusion	22
References	24

List of Figures

1	Original image in grayscale	2
2	Frequency spectrum with magnitudes	3
3	Low-pass filter masks with different radii	3
4	Frequency spectra after applying low-pass filters with different radii	3
5	Low-pass filtered images	5
6	Details of low-pass filtered images	6
7	High-pass filter masks with different radii	7
8	Frequency spectra after applying high-pass filters with different radii	7
9	High-pass filtered images	8
10	Details of high-pass filtered images	9
11	Image compression with Fourier Transform at different levels of coefficient reduction	12
12	Comparison of original images and those after dimensionality reduction	14
13	Variance explained by principal components	14
14	Original images alongside the reconstructed images for different values of k.	15
15	The three images used in this task	16
16	Grayscale image, gradient image and HOG feature image of the three images . . .	16
17	Visualized HOG features, varying orientations, cell size and block size	17
18	The three images used in this task	18
19	LBP Images and Histograms for the three images used	18
20	Images before and after blob detection with increased threshold, higher min-area, and increased circularity	21
21	Histogram of contour numbers per picture	23
22	Scatter plot of contour detection positions and sizes	23
23	Images before and after Gaussian-blur	23

List of Tables

1	Mapping of average statistics and results after blob detection with selected parameters	21
2	Statistics of contour detection with and without Gaussian blur	22

1 Changelog

For the revised version of Assignment 2, we have addressed the feedback given. Below is a list of improvements.

Fourier Transform

- Improved the comparison and trade-offs on sections for low-pass and high-pass filters.
- Improved explanation of added noise in low-pass filtered images, i.e. Gibbs phenomenon.
- Added several images of low-pass and high-pass filtered images, and images of details.
- Improved the section on the advantage of image compression with Fourier Transform with an explanation of Parseval's theorem.

PCA

- For Figure 13, we added dotted lines to better illustrate the variance for the different k values we discuss in the Visual Analysis part.
- The second to last paragraph in the section 3.3 Visual Analysis was also edited, to explain and refer to this new figure.

HOG features

- Added examples showing the impact of changing orientations and block size, in addition to cell size.
- Reported the parameters used to get HOG in figure 16 (formerly figure 12).

LBP

- Added the LBP images and histograms of Local Binary Patterns. Expanded the discussion comparing the types of images.

Blob detection

- Added relevant examples from when parameter changes were made through Table 1 and Figure 20. Most parameter changes ended with 0 blobs so these were not included.

Contour detection

- Added relevant examples from when parameter changes were made through Table 2, Figures 21, 22, and 23. Most parameter changes ended with the model being unable to distinguish contours at all, so these were not included.

2 Fourier Transform

2.1 Frequency Spectrum

To convert a colored image with RGB values, the mean of the three was measured for each pixel. To examine the frequency spectrum with magnitude of the grayscale image, we utilized NumPy's `fft` module. Since the image is 2-dimensional, the discrete `fft2` transformation was used. The function calculates the Fourier transform of each row first and then calculates the Fourier transform of each column of the result - or vice versa, the exact implementation is not known to us, but the functionality remains the same. This aims to generate the landscape of pixel values in the form of sine and cosine waves with different frequencies and phases as complex values.

We plotted the result as a frequency spectrum showing the magnitudes of the different frequency components. Figure 1 shows the original image converted to grayscale. Its shape is 596*894 pixels. Figure 2 shows the frequency spectrum with magnitudes of the image after Fourier transformation. It is common practice to shift the zero-frequency/DC component from the top-left corner to the center, which is also shown. Frequency in the context of a grayscale image means the variation in pixel intensity.

The shifted frequency spectrum is divided into quadrants. The **bottom-right** quadrant contains positive horizontal and vertical frequencies (row and column), the **top-left** quadrant contains negative horizontal and vertical frequencies, the **bottom-left** quadrant contains negative horizontal and positive vertical frequencies, and the **top-right** quadrant contains positive horizontal and negative vertical frequencies. The low frequencies are surrounding the center of the spectrum, while the high frequencies are close to the edges. The DC component (bright spot in the middle) is the average pixel intensity of the image.

It is normal for natural images to have "decaying" frequencies, meaning more of lower frequencies than higher frequencies¹. This can be seen in our shifted frequency spectrum as well with brightness around the center. The bright vertical and horizontal line indicates strong vertical and horizontal frequencies in the image. The diagonal lines indicate diagonal patterns or edges in the image. This can be verified in the image as well. We can, for instance, see that her arm is at an angle with sharp transitions between bright and dark.



Figure 1: Original image in grayscale

¹Wronski 2021.

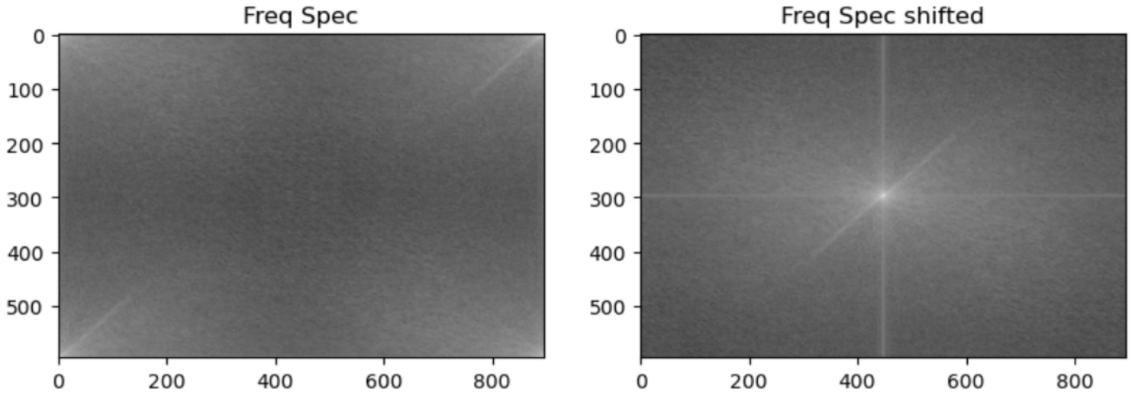


Figure 2: Frequency spectrum with magnitudes

2.2 Low-Pass Filter

After the image is transformed into the frequency domain, it is possible to filter the image based on frequencies. A low-pass filter filters out higher frequencies. To filter the image in the frequency domain, the Fourier coefficients are multiplied by a filter mask. For a low-pass filter, the filter mask has 1s where the desired coefficients are and 0s where the undesired coefficients are. When the Fourier coefficients are rearranged to center the zero component, the filter mask should have 1s near the center of the frequency spectrum and 0s elsewhere. The filter masks were created by setting the elements within a centered circle with radii of 200, 100 and 50 to 1 and 0 elsewhere.

Figure 3 shows the filter masks and Figure 4 shows the frequency spectrum after applying the filters.

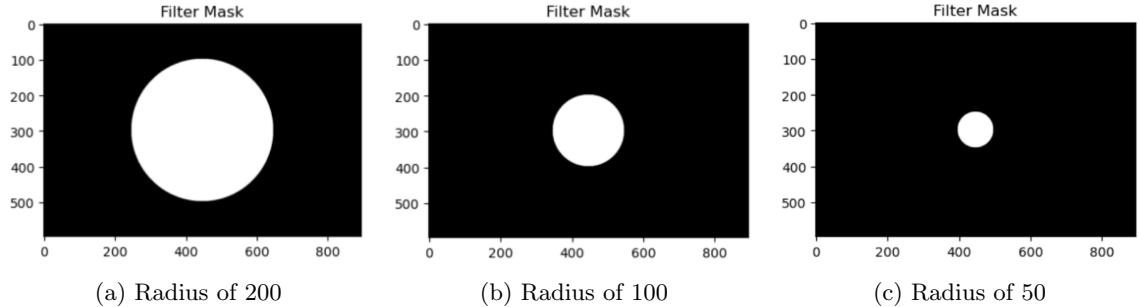


Figure 3: Low-pass filter masks with different radii

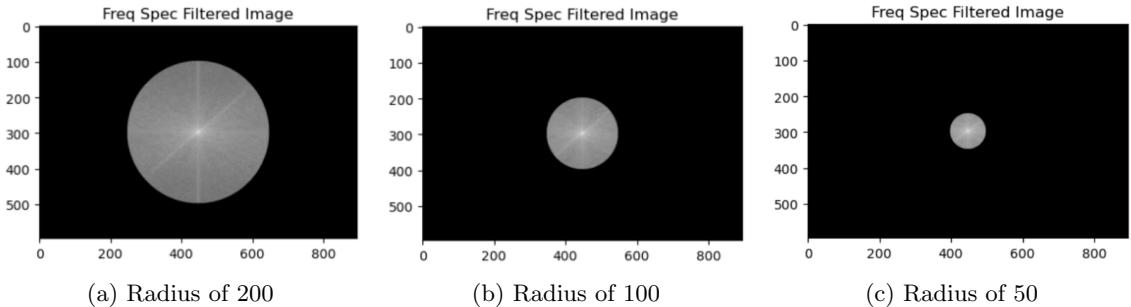


Figure 4: Frequency spectra after applying low-pass filters with different radii

The Fourier coefficients can be transformed back to an image by applying the inverse transform function `ifft2` which calculates the pixel values. The filtered images are shown in Figure 5 along with details in Figure 6. In the first detail image, Figure 6a, a filter mask with a radius of 200 was used. The individual strands of hair are visible, although at a worse quality than the original image. For the next case with a radius of 100, the strands of hair are not visible. It is visible that sharp transitions, such as strands of hair in front of a background, have been smoothed out. In the last case, with a radius of 50, the detailed pattern on the belt is no longer visible but has been smoothed out.

The low frequencies contain a great amount of information, so even though a large portion of the frequency domain has been filtered out, the image is quite similar to the original image. Low-pass filtering can reduce high-frequent noise in an image, e.g. salt-and-pepper noise and digital sensor grain. The low-pass filtering involves a trade-off between reducing noise and preserving detail in areas with sharp intensity transitions. For example, in Figure 6a, a larger filter radius of 200 retains details like individual strands of hair, while smaller radii, such as 100 and 50 in Figures 6b and 6c, progressively smooth out fine textures like hair and the belt pattern. This illustrates how low-pass filtering reduces high-frequency noise, but also diminishes sharp transitions, which requires a balance between noise suppression and detail preservation depending on the application.

The low-pass filtering also introduces noise in the image. "Ringing" artifacts can be seen near sharp transitions, which is typical for a low-pass filtered signal². The ringing artifacts are a result of "Gibbs phenomenon", which happens at jump discontinuities in the frequency domain³. A solution for removing the ringing artifacts is to increase the portion of the frequency range that is kept in the filtering process. Another solution is low-pass filtering without a sharp cutoff in the filter mask. Instead, using a filter with a smooth, gradual cutoff would reduce the likelihood of ringing artifacts⁴.

² *Ringing artifacts* 2024.

³ *Gibbs phenomenon* 2024.

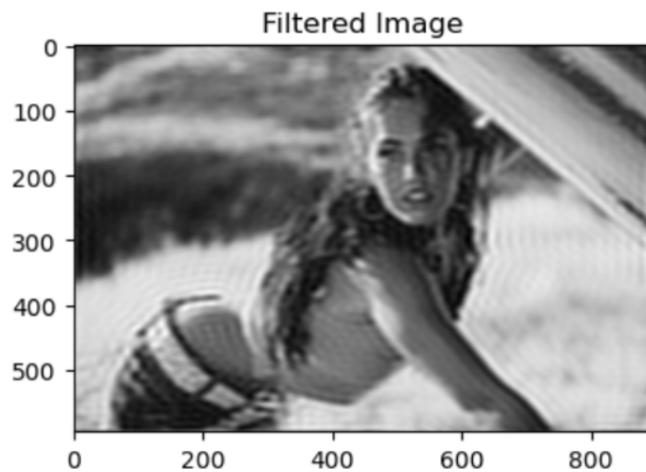
⁴ *Low-pass filter* 2024.



(a) Radius of 200



(b) Radius of 100



(c) Radius of 50

Figure 5: Low-pass filtered images



Figure 6: Details of low-pass filtered images

2.3 High-Pass Filter

The opposite filter of a low-pass filter as previously demonstrated is a high-pass filter. Filtering out the lower frequencies can be done in the exact same way with a filter mask by switching the 1s and 0s. Figure 7 shows the filter masks for high-pass filter and Figure 8 shows the frequency spectra after applying the filter masks. The filter masks in this example filters out only the lowest frequencies in the same way as the low-pass filters did the opposite; the radii of the circles of 1s are 10, 20 and 50.

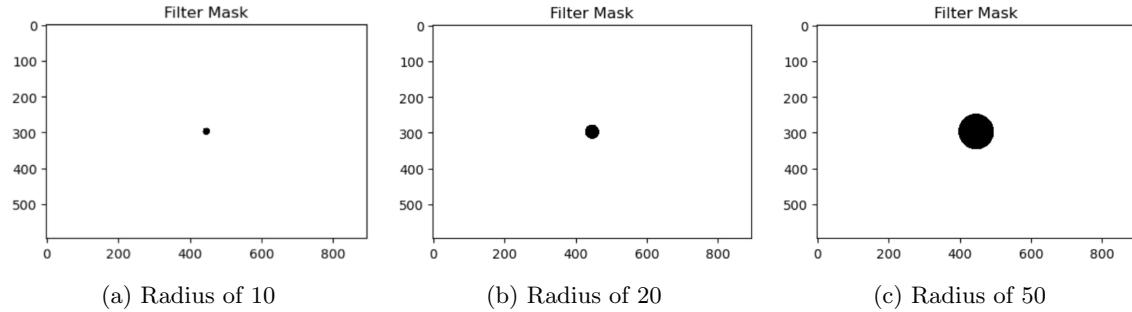


Figure 7: High-pass filter masks with different radii

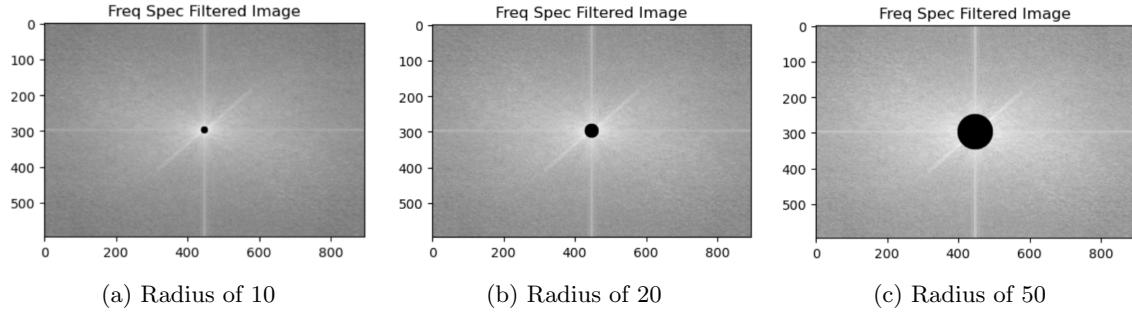


Figure 8: Frequency spectra after applying high-pass filters with different radii

The images after inverse transformation from the frequency domain are shown in Figure 9 with details of each filtered imaged in Figure 10. High-pass filtered images enhance sharp transitions, such as edges and fine details, while filtering out smooth patterns and low-frequency components. For example, in Figure 10a, a smaller radius of 10 preserves edges like contours of the face and hair, but the image appears stark and lacks tonal gradients. As the radius increases, as in Figures 10b and 10c, only more intricate textures, such as the belt pattern, are retained, providing additional fine detail. This makes high-pass filtering ideal for edge detection and highlighting fine structures. However, the loss of low-frequency components causes the image to appear less recognizable overall, highlighting the important role of low frequencies in maintaining the image's structure and coherence.

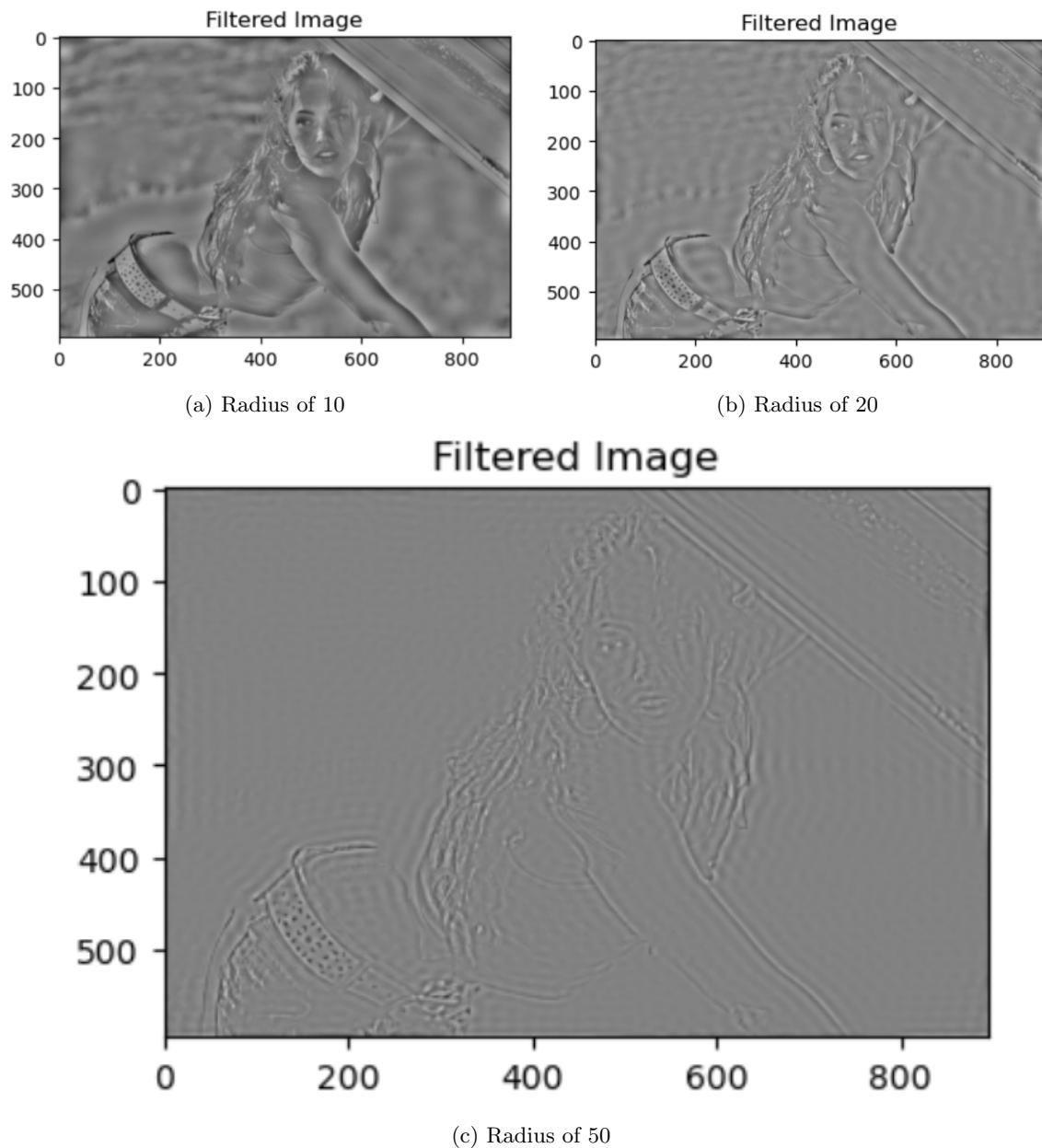


Figure 9: High-pass filtered images

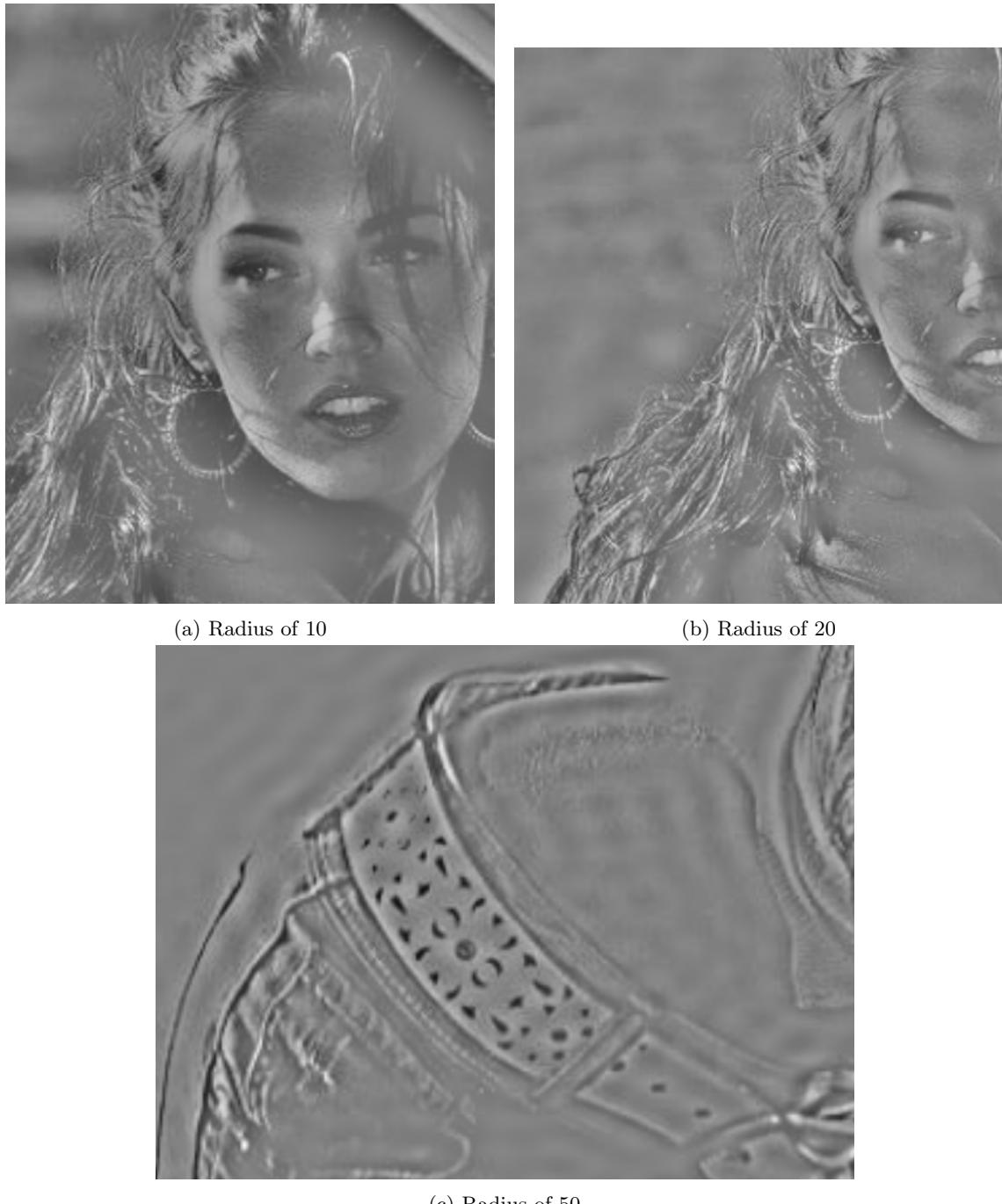


Figure 10: Details of high-pass filtered images

2.4 Image Compression with Fourier Transform

Fourier Transform can be used for image compression by removing the coefficients that contribute less to the representation of the image. The remaining coefficients are stored or transferred. Afterward, the inverse transform of the coefficients brings the image back to the full pixel resolution, but with a lower quality since the compression is lossy.

After transforming the image to Fourier coefficients, the frequencies are sorted based on their magnitude in descending order. Based on the compression ratio, i.e. the number of coefficients to keep, the smaller coefficients are zeroed out. When the image is to be reconstructed, the coefficients are rearranged in a matrix and inverse-transformed back to an image with pixel values.

To accomplish this compression based on percentages, the `argsort()` function of NumPy was used with `flatten()` to sort the coefficients. A threshold value was obtained by storing the value of the lowest coefficient to keep. The threshold value was used to create a mask of the coefficient matrix to zero out the values below the threshold.

Figure 11 shows the image after compression with different ratios. The compression ratio is 2, 3 1/3, 10, and 100, respectively. There is no noticeable reduction in the image quality when reducing down to 50% or 30%. A reduction of coefficients down to 10% can still be inverse-transformed back to an image that very closely resembles the original image. When reducing down to 1%, the image becomes grainy.

2.4.1 Advantages of Image Compression with Fourier Transform

The reason behind why it is possible to reduce the number of coefficients down to 30% in this case and still produce an image without noticeably quality reduction, lies in Parseval's theorem. Parseval's theorem states that for a function $f(x)$ with a Fourier transform $\hat{f}(k)$, the total energy, i.e. information, in the time domain is equal to the total energy in the frequency domain:

The equation can be expressed as⁵:

$$\int_{-T/2}^{T/2} f^2(t) dt = \sum_{n=-\infty}^{\infty} |c_n|^2,$$

where:

- $f(t)$: A real-valued periodic function with period T ,
- c_n : The Fourier coefficients of $f(t)$, given by:

$$c_n = \frac{1}{T} \int_{-T/2}^{T/2} f(t) e^{-in\omega_0 t} dt,$$

where $\omega_0 = \frac{2\pi}{T}$ is the fundamental angular frequency.

Parseval's theorem for the Discrete Fourier Transform (DFT) is expressed as:

$$\sum_{n=0}^{N-1} |f[n]|^2 = \frac{1}{N} \sum_{k=0}^{N-1} |F[k]|^2,$$

where:

- $f[n]$: The discrete-time signal of length N ,
- $F[k]$: The DFT coefficients of $f[n]$, given by:

$$F[k] = \sum_{n=0}^{N-1} f[n] e^{-i \frac{2\pi}{N} kn}.$$

Since the amount of energy/information is contained in the sum of squares of Fourier coefficients, the larger coefficients contribute significantly more to the "total energy" than the smaller coefficients. Therefore, the smaller coefficients can be removed, i.e. zeroed out, and the information is only reduced slightly. This is why the images with coefficients reduced to 50% and 30% look almost identical to the original.

The compression ratio and output quality are not the same for every image. The higher resolution the original image has, the more information can be removed, i.e. coefficients, and still produce a satisfying result. This is because of a higher ratio of redundant information⁶. For this exact image with a resolution of 596*894 pixels, a reduction down to 10% is satisfying for the image size in the report.

⁵Parseval's Theorem 2024.

⁶Brunton 2024b.

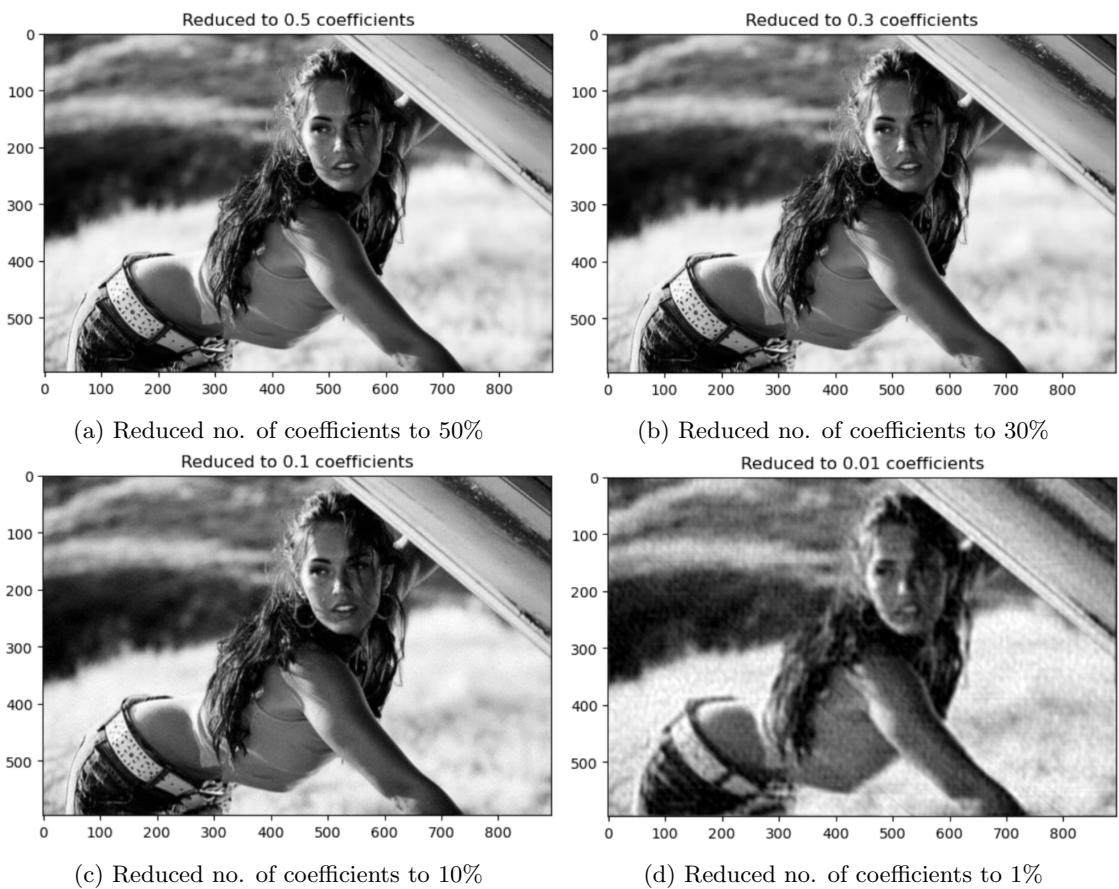


Figure 11: Image compression with Fourier Transform at different levels of coefficient reduction

3 PCA

For this assignment, we selected the *Stranger Things Faces Dataset Grayscale* from Kaggle, featuring 620 grayscale images of 11 characters from the TV series *Stranger Things*⁷.

After loading the images into our program (in PIL format), our PCA function took two parameters: `images_array` (grayscale images) and k (number of principal components). First, we converted each image to a NumPy array using `np.array()` and then flattened it into a 1D array using `flatten()`. The flattened images were combined into a 2D array, where each row represented an image and each column represented a pixel, forming a matrix with dimensions 620×7396 . To normalize the pixel values, we divided each value by 255, scaling them to a range of $[0, 1]$ ⁸.

Next, we centered the data by computing the mean for each pixel and subtracting it from each image using NumPy's mean subtraction (`images_array_2d - mean`), ensuring that PCA focused on variations in pixel intensities rather than their absolute values⁹.

To capture relationships between pixels, we computed the covariance matrix using `np.cov()` on the centered data. The covariance matrix had dimensions 7396×7396 , representing pixel relationships across the entire dataset.

From this covariance matrix, we calculated the eigenvalues and eigenvectors using `np.linalg.eig()`, which helped us identify the principal components. Sorting the eigenvalues in descending order allowed us to identify the most significant components. We then selected the top k eigenvectors, which represented the directions with the most variance in the dataset.

Finally, we projected the images onto the lower-dimensional subspace formed by these top k eigenvectors using matrix multiplication `np.dot(centered_images, eigenvectors_k)`, reducing each image to k components instead of the original 7396 pixels. The results were stored in the `projected_images` array, representing the compressed versions of the images.

3.1 Reconstruction of Images

When reconstructing the images, we chose to use the top 50 principal components ($k = 50$). This represents a significant reduction from the original 7,396 features. After applying PCA, we clearly observed a loss in detail and sharpness. The images appeared blurry, and it became more difficult to recognize the individuals in them. However, PCA effectively retained the maximum variance in the dataset. While finer details, such as skin texture and wrinkles, were lost, the overall face structure and prominent facial features like the eyes, nose, and mouth were well preserved. In this case, the variance retained was 89.86%.

Figure 12a shows a selection of the original images before PCA was applied, and Figure 12b illustrates the images after dimensionality reduction to $k = 50$, highlighting the loss in finer details while preserving key facial features.

3.2 Experimentation

When experimenting with different values of k , we wanted to see how PCA performed with k values both below and above 50. It is generally recommended to aim to retain enough components to explain around 90-95% of the variance.¹⁰.

From the variance explained plot (see Figure 13) across different values of k , we observe a sharp rise in the variance explained up to about 100 components. Beyond this, the curve begins to flatten, meaning that each additional component contributes less to the overall variance.

⁷Kay 2024.

⁸Harsh 2024.

⁹Dey 2024.

¹⁰AI 2024.



(a) A selection of the original images.

(b) Dimension reducted images, $k = 50$

Figure 12: Comparison of original images and those after dimensionality reduction

By around 400 components, the variance explained approaches 100%. To balance compression and quality, the optimal number of components is likely to be around 100-150.

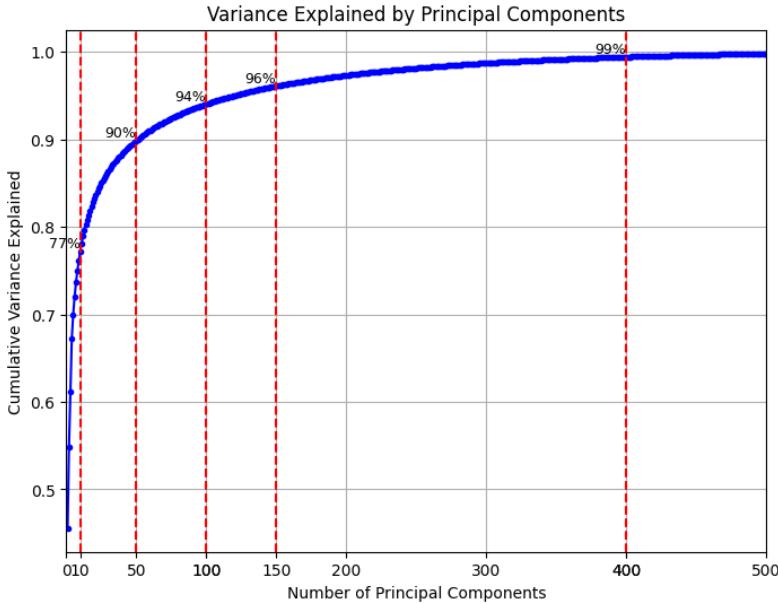


Figure 13: Variance explained by principal components

3.3 Visual Analysis

Knowing this, we looked at images with different numbers of principal components. For images reconstructed with only 10 components, a significant amount of information is lost. The trade-off between compression and quality is too high, resulting in blurred and unrecognizable images.

At 50 components, the quality improves but still lacks clarity. Moving to 100 components, we see a clear improvement in quality and information retained. Distinct facial features such as eyes, nose, and mouth start to become more visible, and the edges become more prominent. Although the images remain slightly blurry, the information loss is moderate, and the individuals become recognizable. At this point, we are explaining approximately 94% of the variance, aligning with our goal of retaining 90-95% variance for an ideal balance between quality and compression.

Increasing to 120 components, the improvement is minimal compared to 100 components, as the explained variance increases by only about 1%. However, at 400 components, the reconstructed images are almost indistinguishable from the originals, with fine details like textures, edges, and contours becoming much clearer.

Figure 14 illustrates the original images alongside the reconstructed images for different values of k , showing the progression in quality as the number of principal components increases. Figure 13 shows how much cumulative variance is explained for each of these values of k , with the percentages rounded for clarity. For instance, 10 components explain approximately 77% of the variance, 50 components explain 90%, 100 components explain 94%, and 400 components explain 99%, highlighting the diminishing returns in quality improvement beyond 100-150 components.

To conclude, aiming for 95% explained variance seems ideal when balancing quality and compression, which corresponds to retaining around 100-150 principal components.

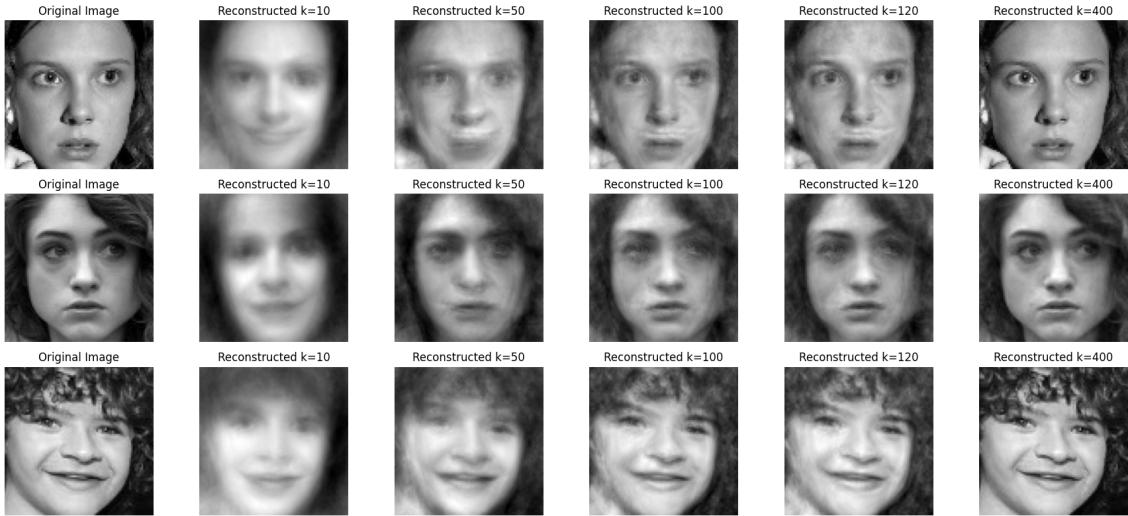


Figure 14: Original images alongside the reconstructed images for different values of k .

3.4 Error Analysis

As we varied the number of principal components, the MSE changed accordingly. Lower values of k (indicating higher compression) resulted in higher MSE, demonstrating greater information loss. On the other hand, higher values of k (indicating less compression) produced lower MSE, suggesting that more information was retained in the reconstructions.

The MSE values we obtained indicate a clear relationship between the number of principal components and the reconstruction error. With only 10 components, the MSE is relatively high (0.00920), indicating significant information loss. As the number of components increased to 100, the MSE dropped to 0.00410, and further reduced to 0.00241 with 150 components. Interestingly, the MSE remained constant at 0.00241 between 150 and 400 components, suggesting that the additional components beyond 150 contribute very little to the reconstruction. This observation strengthens our hypothesis that, beyond a certain point, additional principal components have minimal impact on the visual quality of the image. This implies that around 150 components are sufficient to capture nearly all the significant variance in the images.

Finally, at 1000 components, the MSE reaches 0.0000, indicating close to perfect reconstruction. The results align with PCA behavior we have seen earlier, where after a certain point, additional components do not significantly enhance reconstruction quality.

4 HOG features

4.1 Figures and results



Figure 15: The three images used in this task

Visualization of HOG image and gradient image

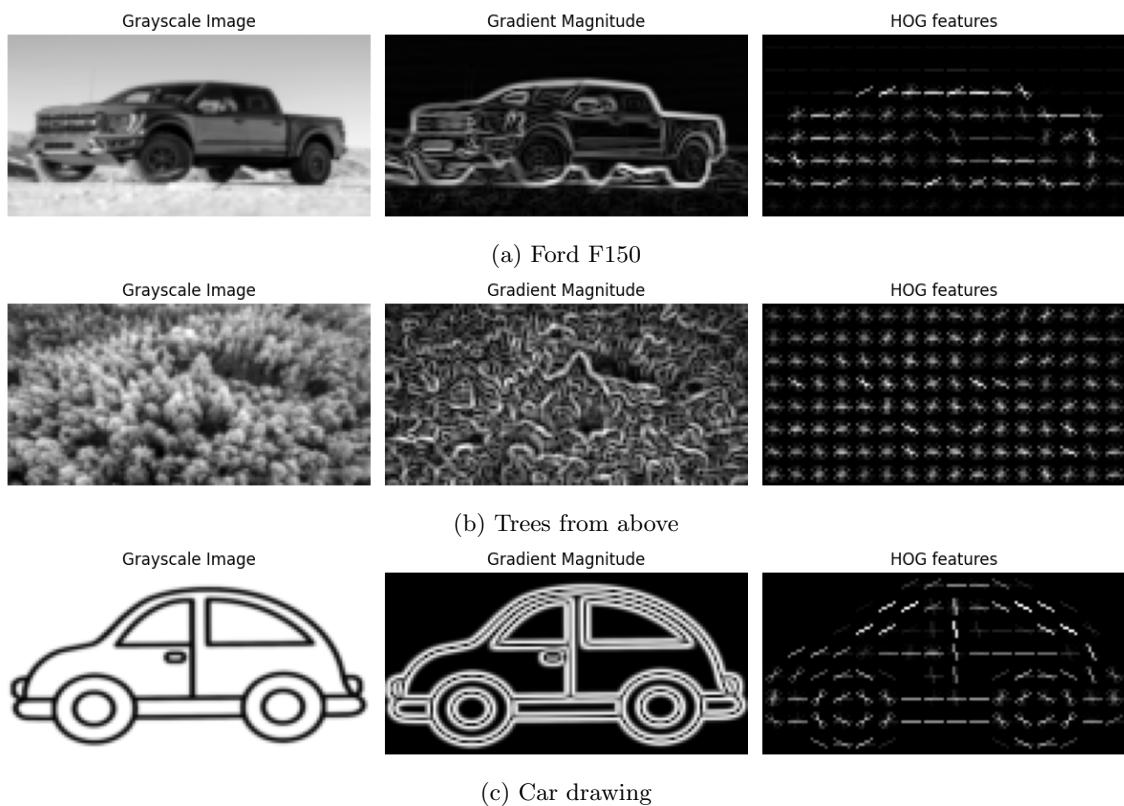


Figure 16: Grayscale image, gradient image and HOG feature image of the three images

All images were reduced to images with (64x128) pixels, then converted to grayscale images. The gradients of the images were produced by applying Sobel filters to the images. The grayscale conversion, Sobel filters and computation of HOG features were all computed with the help of the scikit-image library. The Sobel operator for computing gradients and edges is quite simple and time effective compared to other edge detection operations such as Canny.¹¹. When computing the HOG-features in figure 16 the parameters were set as follows; `Orientations:9, Pixels per cell:8, Cells per block:2`

As the drawing of a car has more clear edges, and is only black on white, the gradient image is well-defined. The same goes for the HOG features. On the other hand, the aerial photo of a forest

¹¹Haidar 2021

is highly textured and the HOG captures local gradients but fails to provide a coherent shape representation. This illustrates a weakness of HOG, as it is well suited for object detection when the objective is to identify clear, structured shapes, but it may struggle with scenes where objects are highly textured, densely packed or lack clear boundaries.

4.2 Parameters discussion

Varying the parameters cell size, block size and number of bins yielded very different results, as seen in figure 17. With smaller cells, the resulting HOG was significantly more accurate than with large cells. However, smaller cells leads to higher computational cost and more noise sensitive result, as there are more feature vectors, and slight variations in pixel intensities are more prominent. Similarly, with a smaller block size, the spatial resolution of the image is increased, and so is the computation. With larger block sizes, the resulting HOG features are more noise sensitive. From the results, we can deduce that having larger cells and small blocks are well suited for detecting clear shapes. On the other hand small cells and large blocks are better suited for images with a lot of information. Reducing cell size and increasing block size will lead to higher computational cost.

The amount of bins determines how the gradients within a cell is divided, meaning that fewer bins result in fewer directions within the cells. With 2 bins, edges are only visualized in two directions, and it is very difficult to capture differences in edges. Increasing the number of orientation bins, will lead to edges being detected in more directions.

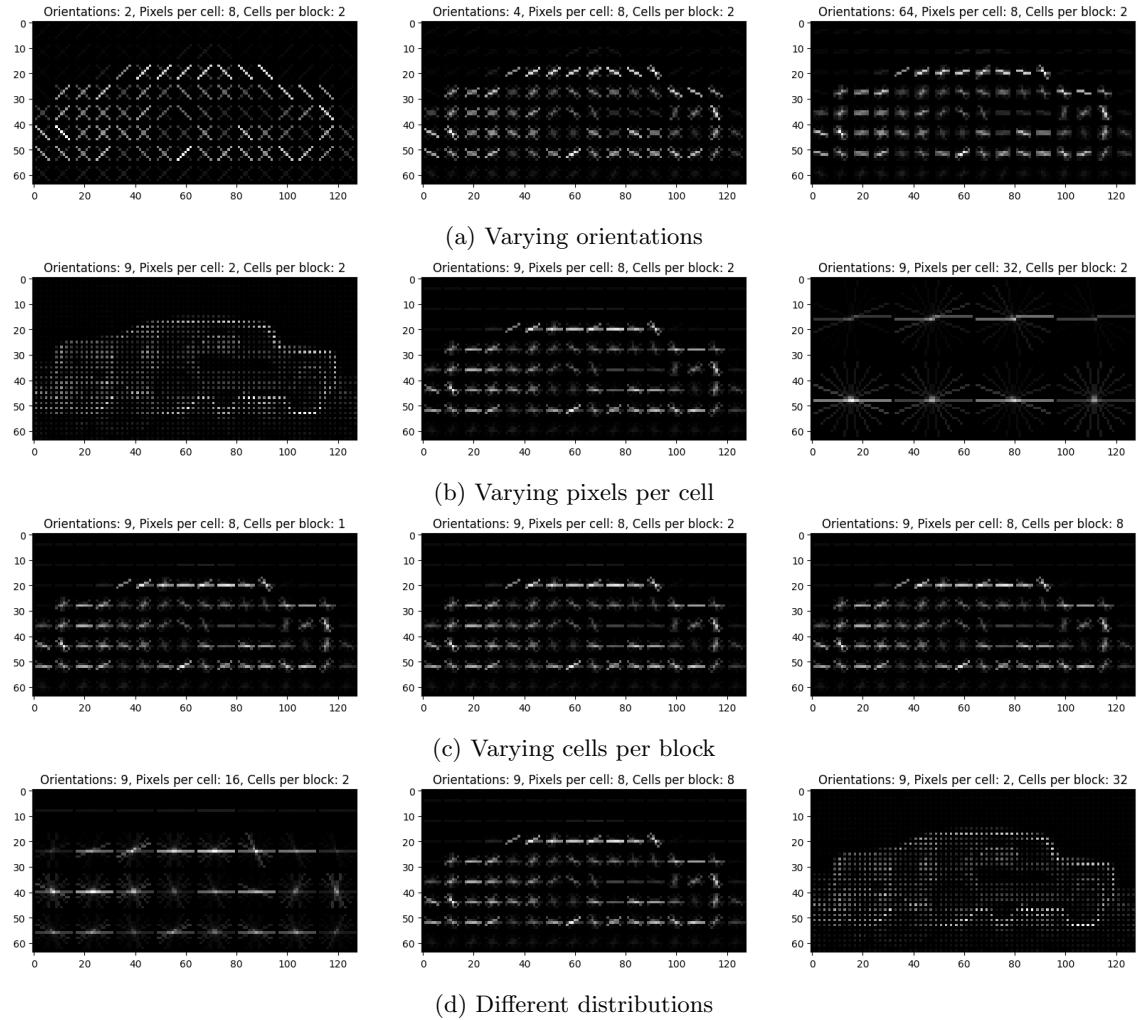
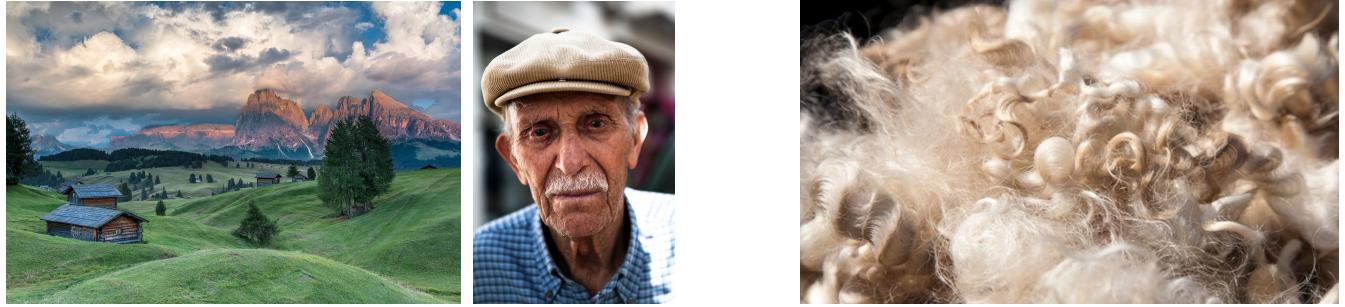


Figure 17: Visualized HOG features, varying orientations, cell size and block size

5 Local Binary Patterns

5.1 Images used and method



(a) Landscape in Italy

(b) Photography of a man

(c) Wool

Figure 18: The three images used in this task

The histogram of the LBP (*Local Binary Patterns*) images yields a good representation of the contrasts in the image. When using the basic 8-neighbor method, each pixel in the image is compared to its eight neighbor pixels, and for each pixel with a greater value than the center, one puts a "1", and a "0" otherwise. This is done in the same pattern for all pixels, and the 1's and 0's represent a binary string, with values from 0 to 255 when represented as decimal values. The x-values in the histogram ranges from 0 to 255, and the y-values represent how many occurrences there are of each x-value. If there are many values at 255, it can indicate for instance rough surfaces or very similar pixel values for neighboring pixels. As a consequence, with the three images used in the task, the amount of 255-values can be expected to be higher for 18a and 18b than for 18c.

5.2 Histograms and discussion

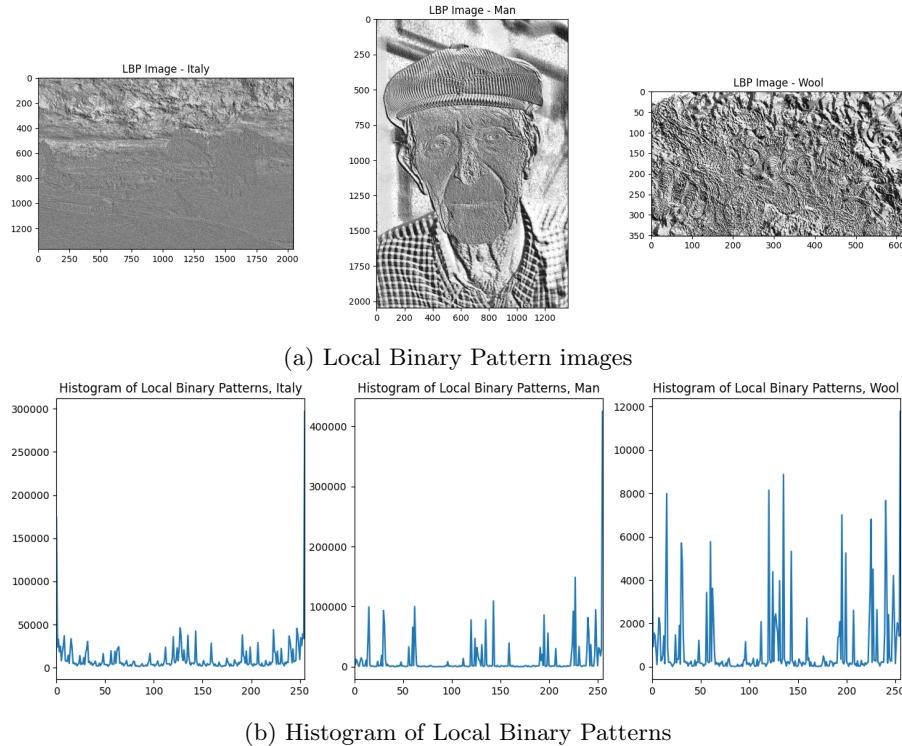


Figure 19: LBP Images and Histograms for the three images used

From Figure 19b, it is evident that the histogram of the Local Binary Pattern (LBP) for the wool image exhibits significantly more pronounced texture than the other two images. This highlights the high level of detail and variation in the wool texture, which the LBP effectively captures using the basic 8-neighbor method. In contrast, while there are contrasts in the Italian landscape image and the portrait, these contrasts are less distinct. As a result, they are not as prominently captured by the basic LBP method, which relies on clear local intensity variations within an 8-pixel neighborhood.

The lack of pronounced texture in the landscape and portrait images becomes even more apparent when comparing their corresponding LBP images in Figure 19a. The histograms for these two images feature prominent peaks at the pixel value 255, indicating uniform or flat regions in the images where minimal intensity variations occur. Beyond this dominant peak, the distributions for the landscape and portrait images remain relatively flat, reflecting a limited range of detectable textures.

This difference in histogram behavior underscores the sensitivity of the basic LBP method to highly textured patterns, as seen in the wool image, while it struggles to effectively capture subtle or uniform textures in the landscape and portrait images. This limitation stems from the fact that the basic LBP method does not account for rotation invariance or extended neighborhood relationships, which may better represent certain types of textures.

Had an alternative LBP method been employed, such as Rotation-Invariant LBP or Extended LBP, the resulting histograms would likely exhibit a broader distribution of peaks across different intensity values.¹² For example, the Italian landscape image, which features directional elements like hills and mountains, might display more nuanced texture patterns with a rotation-invariant approach. Similarly, an extended LBP method, which considers larger neighborhoods, could capture more complex patterns in the portrait, potentially revealing additional detail that the basic method overlooks.

These observations suggest that the choice of LBP method has a significant impact on texture representation and feature extraction. While the basic LBP method is effective for highly textured surfaces, more advanced variants might be better suited for images with less pronounced or more diverse textural characteristics. Future analyses could benefit from testing these alternative methods to evaluate their ability to enhance texture representation for various image types.

¹²Pemalu 2024

6 Blob Detection

The most used parameters for blob detection are defined by **threshold**, **convexity**, **area**, **circularity** and **inertia**. We used the cv2 library to create a `SimpleBlobDetector()`. Through iterating over the pictures in the dataset we detected blobs for each picture.

6.1 Parameters discussion

Threshold operates with a min and max value that the blob-detection algorithm uses to determine which pixels to discard from a blob. A wider range allows more blobs with varying intensity, while a narrow range focuses on a specific intensity. We discovered that for the facial gray-scale images from `strangerthings` dataset the amount of blobs pr. picture increased from mostly 0-2 blobs per picture with `min=70, max=350` to 2-4 blobs per picture with `min=30-220`. We also tried to increase / decrease the range which also resulted in fewer blobs per picture.

Area ensures that only blobs within the specified size range are detected. It helps to exclude noise (too small blobs) or irrelevant large areas (parts of the background or very large objects). For this parameter we chose the range 30-200. We observed that by increasing the lower-bound too much we lost blobs per picture. On the other hand we observed that increasing the upper-bound did not really change blobs per image. This makes sense as we resized the images to a 70px by 70px, and increasing upper-bound does not really change things. By decreasing the lower-bound too much we got way too many blobs and did not represent the picture.

Circularity helps to detect circular objects and discard blobs that are irregularly shaped or elongated. However with the min-ratio set to 0.3 there was minimal difference in number of blobs per picture when we turned the parameter off. On the other hand, when we turned the min-ratio up to 0.4 or more the number of blobs per picture started to decrease a lot, and we lost accuracy. This relates to the fact that the pictures did not consist of a lot of circular-shaped objects.

Convexity helps detect circular or mostly convex objects. Therefore, we ended up with disabling this parameter. When trying out the min-ratio 0.2 we already saw a decrease in the number of blobs per picture. When increasing the parameter we ended up with zero blobs per picture. As a result, we removed this parameter.

Inertia is a measure of how elongated a blob is. It describes the distribution of the blob's pixels around its axis. This is also a parameter used to detect circular objects. In that case, performance on the amount of blobs detected decreased with turning on the parameter. It also decreased more with a higher min-ratio.¹³

6.2 Conclusion

In conclusion the parameters that stood out as most important in a blob-detection algorithm for these types of face cards were **threshold** and **area**. We saw some improvement by including the **circularity** parameter, but these were minimal. The **convexity** and **inertia** parameters were discarded as they were not of use in this particular dataset.

¹³*Blob Detection Using OpenCV (Python, C++)* 2024.

Statistic	Value	Circularity	Area (min, max)	Threshold (min, max)
Average number of blobs per image	0.49	0.4	50, 200	70, 350
Average blob size	11.30	0.4	50, 200	70, 350
Max number of blobs in an image	5	0.4	50, 200	70, 350
Min number of blobs in an image	0	0.4	50, 200	70, 350
Average number of blobs per image	2.02	0.3	30, 200	30, 220
Average blob size	10.26	0.3	30, 200	30, 220
Max number of blobs in an image	7	0.3	30, 200	30, 220
Min number of blobs in an image	0	0.3	30, 200	30, 220

Table 1: Mapping of average statistics and results after blob detection with selected parameters



(a) Blob detection result with best parameters



(b) Blob detection result with increased threshold etc.

Figure 20: Images before and after blob detection with increased threshold, higher min-area, and increased circularity

7 Contour Detection

Regarding the chosen dataset the clear winner algorithm was contour detection. Which, given the dataset, is not surprising. Images of faces do not often behave as round objects that are easily separated / detected. However all faces have contrasts often to face-features or the background which served as a good dataset for contour detection.

7.1 Advantages and Limitations

There are both advantages and limitations for each algorithm. For blob detection an advantage is that blob detection can detect regions that are not necessarily of a specific shape. It is shape-independent. In addition it works well for spotting round objects. On the other hand, the algorithm is somewhat limited to convex shapes. Concave objects are much harder for the algorithm to detect. Also, blob detection might not be effective when objects have sharp or irregular edges.

Regarding the contour detection algorithm it is good at finding the precise outlines of objects, making it great for objects with well-defined edges. Contours also give detailed information about object shape, allowing for precise shape analysis, area, and perimeter calculations. On the contrary, contour detection can be very sensitive to noise or small fluctuations in the image. Finally, to get good contour detection, preprocessing steps like thresholding, blurring, or edge detection are often needed, which can complicate the process.

7.2 Parameters discussion

Regarding the threshold values the model tends to overfit the model for values lower than 100. The model tends to underfit for values over 100 and especially over. The threshold turns pixels underneath that colour to 0 and others over to 255¹⁴. Using the threshold together with *THRESH_BINARY* worked by far the best as *THRESH_TOZERO* was not able to distinguish contours at all. Neither was *THRESH_TRUNC*. As no distinguishable contours were found, examples of this method are left out.

For the `cv2.findContours` method we selected parameters *RETR_EXTERNAL* as *RETR_TREE* and *RETR_CCOMP* both overfit the contours. As mentioned above, contour detection often requires some kind of preprocessing. The quality of the contours improved significantly by applying `cv2.GaussianBlur` method with a 5x5-kernel. In Figure 23 the differences in results are noticeable.

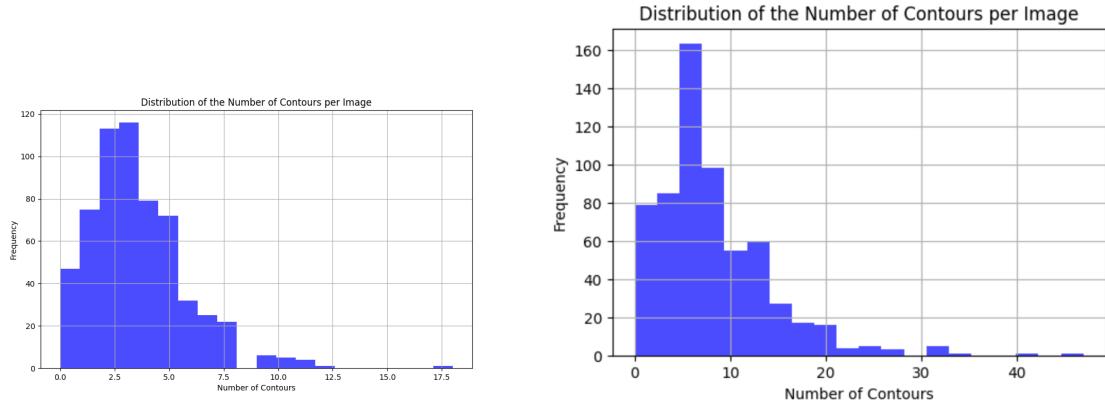
7.3 Visual representation and conclusion

Contour detection is advantageous in detecting and segmenting objects with well-defined boundaries, like characters in an image, mechanical parts in an assembly, or shapes in a logo. On the other hand, blob detection works well with detecting round spots as in for example astronomy images (stars, planets) or in biological microscopy images.

Statistic	With Gaussian blur	Without Gaussian blur
Average number of contours per image	3.42	8.30
Average contour area	373.77	152.04
Average contour perimeter	67.74	34.87
Max number of contours in an image	18	47
Min number of contours in an image	0	0

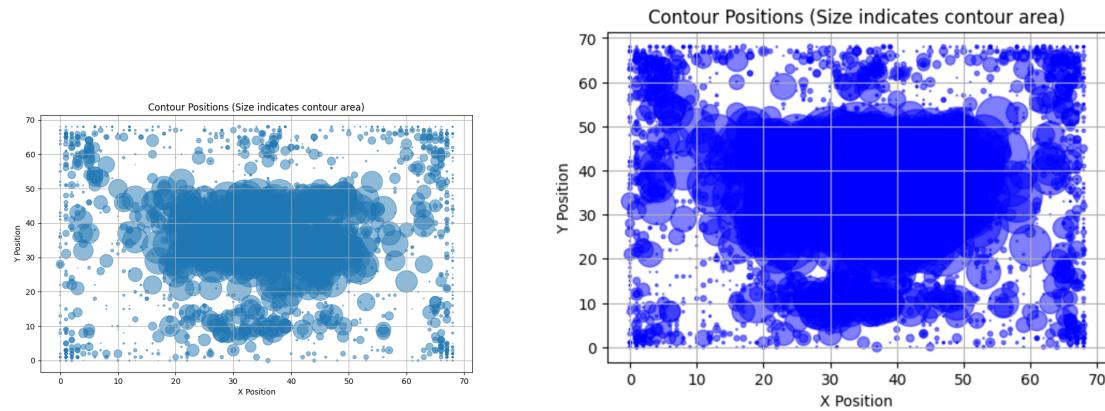
Table 2: Statistics of contour detection with and without Gaussian blur

¹⁴*Image Thresholding in OpenCV 2024.*



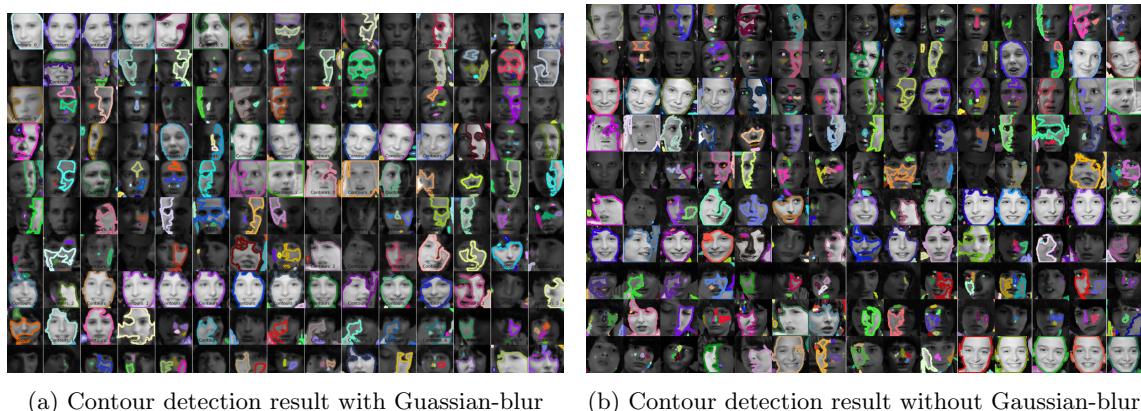
(a) Contour detection histogram with concluded parameters (b) Contour detection histogram without gaussian-blur

Figure 21: Histogram of contour numbers per picture



(a) Contour detection positions and sizes with concluded parameters (b) Contour detection positions and sizes without Gaussian-blur

Figure 22: Scatter plot of contour detection positions and sizes



(a) Contour detection result with Guassian-blur (b) Contour detection result without Gaussian-blur

Figure 23: Images before and after Gaussian-blur

References

- AI, Team Applied (2024). *Principal Component Analysis (PCA) Explained*. URL: <https://www.appliedaicourse.com/blog/principal-component-analysis-pca/>. (visited on 23rd Oct. 2024).
- Blob Detection Using OpenCV (Python, C++) (2024). URL: <https://learnopencv.com/blob-detection-using-opencv-python-c/> (visited on 23rd Oct. 2024).
- Brunton, Steve (2024a). *Image Compression and the FFT*. URL: <https://www.youtube.com/watch?v=gGEBUDM0PVc> (visited on 25th Oct. 2024).
- (2024b). *Image Compression and the FFT (Examples in Python)*. URL: <https://www.youtube.com/watch?v=uB3v6n8t2dQ> (visited on 25th Oct. 2024).
- Dey, Roshmita (2024). *Understanding Principal Component Analysis (PCA)*. URL: <https://medium.com/@roshmitadey/understanding-principal-component-analysis-pca-d4bb40e12d33#:~=Before%20performing%20PCA%2C%20it%27s%20essential,equal%20importance%20in%20the%20analysis> (visited on 23rd Oct. 2024).
- Gibbs phenomenon (2024). URL: https://en.wikipedia.org/wiki/Gibbs_phenomenon (visited on 16th Nov. 2024).
- Haidar, Lina (2021). *Sobel vs. Canny Edge Detection Techniques: Step by Step Implementation*. URL: <https://medium.com/@haidarlina4/sobel-vs-canny-edge-detection-techniques-step-by-step-implementation-11ae6103a56a> (visited on 24th Oct. 2024).
- Harsh, Patel (2024). *Normalization in Image Preprocessing: Scaling Pixel Values by 1/255*. URL: <https://medium.com/@patelharsh7458/normalization-in-image-preprocessing-scaling-pixel-values-by-1-255-111b2fa496d4> (visited on 23rd Oct. 2024).
- Image Thresholding in OpenCV (2024). URL: <https://learnopencv.com/opencv-threshold-python-cpp/> (visited on 23rd Oct. 2024).
- Jaadi, Zakaria (2024). *Principal Component Analysis (PCA): A Step-by-Step Explanation*. URL: <https://builtin.com/data-science/step-step-explanation-principal-component-analysis> (visited on 23rd Oct. 2024).
- Kay, Alireza (2024). *Stranger Things Faces Dataset Grayscale*. URL: <https://www.kaggle.com/datasets/alirezakay/stranger-things-faces-dataset-grayscale> (visited on 23rd Oct. 2024).
- Low-pass filter (2024). URL: https://en.wikipedia.org/wiki/Low-pass_filter (visited on 25th Oct. 2024).
- Parseval's Theorem (2024). URL: <https://mathworld.wolfram.com/ParsevalsTheorem.html> (visited on 16th Nov. 2024).
- Pemalu, Ikhwan (2024). *Local Binary Patterns (LBP): An In-Depth Exploration of Texture Analysis*. URL: <https://medium.com/@ikhwanpemalu22/local-binary-patterns-lbp-an-in-depth-exploration-of-texture-analysis-13aee7fb2c7> (visited on 25th Oct. 2024).
- Ringing artifacts (2024). URL: https://en.wikipedia.org/wiki/Ringing_artifacts (visited on 25th Oct. 2024).
- Wronski, Bart (2021). *Comparing images in frequency domain. “Spectral loss” – does it make sense?* URL: <https://bartwronski.com/2021/07/06/comparing-images-in-frequency-domain-spectral-loss-does-it-make-sense> (visited on 25th Oct. 2024).