Department of Computer Engineering

Bu-Ali Sina University

Digital Image Processing Course

Assignment 1: Image Zooming, Enhancement, and Transformation

By:

Ali Nafisi

Course Professor:

Professor Hassan Khotanlou

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1 INTRODUCTION

The evolving landscape of digital image processing is fueled by a relentless pursuit to refine and enhance visual content. Within this dynamic field, various methodologies have emerged as indispensable tools for manipulating and optimizing digital images. This project explores important techniques in a structured way, centering on Image Zooming, Image Enhancement, and Affine Transformations. The significance of these operations lies in their ability to address fundamental challenges and harness opportunities inherent in the digital imagery domain.

Image Zooming, the first focal point of this investigation, is a critical operation that aims to magnify images for a closer examination of details. Pixel Replication, Zero-order Hold, and Bilinear Interpolation, the specific methods explored in this category, each contribute distinct approaches with varying computational complexities and visual fidelity trade-offs. The essence of Image Zooming is grounded in its capacity to facilitate detailed analysis and visualization, essential in fields such as medical imaging and computer vision.

Moving on to Image Enhancement, the necessity arises from the imperfections often present in raw digital images. Gamma Correction, Logarithmic Correction, Inverse Logarithmic Correction, and Histogram Equalization, the techniques explored in this category, play pivotal roles in adjusting pixel intensities to improve overall visual appeal. The motivation behind Image Enhancement is to mitigate inherent flaws, correct distortions, and elevate the perceptual quality of images for human or machine interpretation.

Affine Transformations, introduces geometric modifications like Translation and Rotation. These operations are fundamental in accommodating variations in spatial orientation, crucial in tasks ranging from object recognition to image registration. The rationale behind Affine Transformations lies in their ability to provide a flexible framework for adapting images to different contexts and applications.

In sum, the motivation behind these digital image processing operations is grounded in the need to overcome inherent challenges, refine raw imagery, and adapt visual content for diverse applications. As we delve into the methodologies within each category, our aim is to provide a comprehensive understanding of their principles and applications, contributing to the broader discourse on the optimization and interpretation of digital images.

2 METHODOLOGY

2.1 Image Zooming

Zooming is a fundamental concept in image processing that involves enlarging an image to make its details more visible and sharper. It is used in a wide range of applications, from optical zooming through a lens to digital zooming on a computer system. In digital image processing, there are several methods for zooming, including pixel replication, zero-order hold, and Bilinear interpolation.

2.1.1 Pixel Replication

Pixel replication[1], also known as upsampling or nearest neighbor interpolation, is a technique used to increase the size of a digital image by duplicating existing pixels. This process involves creating new pixels based on the values of adjacent pixels in the original image. While pixel replication is a common method for resizing images, it has both advantages and disadvantages. The advantages of pixel replication include:

- **Simple Implementation:** Pixel replication is a straightforward technique, making it easy to implement. It involves copying existing pixel values to create a larger image.
- **Speed:** Upsampling through pixel replication is computationally less intensive compared to more complex interpolation methods. This makes it a faster option for resizing images.
- **Maintains Image Structure:** Since pixel replication duplicates existing pixels, it maintains the basic structure of the original image. This can be beneficial when preserving sharp edges and details is crucial.

However, pixel replication also has some disadvantages:

- **Limited Quality Improvement:** Pixel replication does not introduce new information to the image; it simply duplicates existing pixels. As a result, the upscaled image may appear blocky or pixelated, especially when viewed at larger sizes.
- **Lack of Smoothness:** The simplicity of pixel replication can lead to jagged edges and a lack of smoothness in the upscaled image. This can be particularly noticeable in areas with diagonal lines or curves.
- **Artifacting:** Upsampling with pixel replication can introduce artifacts, such as aliasing or moiré patterns, especially when increasing the image size significantly. These artifacts can degrade image quality.

- **Not Ideal for Continuous-Tone Images:** Pixel replication may not be the best choice for resizing images with continuous-tone elements, such as photographs, because it tends to produce results that lack the subtlety and nuance found in the original.
- **Limited Application in Professional Settings:** In professional graphic design, printing, or photography, where image quality is crucial, pixel replication is often considered a suboptimal method for resizing due to its limitations in maintaining image fidelity.

2.1.2 Zero-order Hold

The zero-order[2] hold method, also referred to as zoom twice, is a technique constrained to doubling the size of an image. The methodology involves selecting two adjacent elements from a row. Following this selection, the chosen elements are summed, and the result is divided by two. Subsequently, the obtained number is positioned between the initially selected adjacent elements. It is important to highlight that this method is to be employed initially along rows and then along columns. The advantages of zero-order hold include:

- **Non-Blurry Images:** Unlike some other methods, this technique does not produce blurry images, ensuring clarity in the resulting image.
- **Ease of Doubling Resolution:** Doubling the image resolution is straightforward with this method, requiring no special effort.
- **Ease of Implementation:** Implementation is easy, and there is zero computation overhead associated with this method.

However, zero-order hold also has some disadvantages:

- **Power of Two Restriction:** This method can only operate effectively on images with dimensions that are powers of two.
- **Lack of Custom Resolution:** Due to its reliance on powers of two, the method does not allow for zooming images at custom resolutions, limiting its flexibility in certain scenarios.

2.1.3 Bilinear Interpolation

Bilinear interpolation[3] is a method used in image processing to estimate the values of pixels at non-integer coordinates. This technique is commonly employed in image zooming, where the goal is to increase the size of an image while preserving its visual quality. Bilinear interpolation calculates the new pixel values by considering the weighted average of the nearest four pixels. The advantages of bilinear interpolation include:

- **Simplicity:** Bilinear interpolation is computationally less demanding compared to more complex interpolation techniques, making it efficient for real-time applications.

- **Smoothness:** The weighted averaging used in bilinear interpolation helps in producing relatively smooth and visually appealing results. This smoothness is beneficial for maintaining image quality during zooming.

However, bilinear interpolation also has some disadvantages:

- **Blurry Edges:** In certain cases, bilinear interpolation can cause blurring, especially when zooming in on images. This is because the weighted averaging may not capture fine details, leading to a loss of sharpness.

- **Limited Accuracy:** Bilinear interpolation assumes that pixel values change linearly between neighboring pixels. This assumption may not hold true for all types of images, especially those with complex patterns or sharp transitions.

- **Artifacting:** Bilinear interpolation can introduce artifacts, such as aliasing or moiré patterns, especially when enlarging images significantly. These artifacts can affect the visual quality of the zoomed image.

2.2 Image Enhancement

Image enhancement techniques play a crucial role in improving the visual quality of images for various applications. In this section, we explore several image enhancement methods employed to refine and optimize the appearance of digital images.

2.2.1 Gamma Correction

Gamma correction[4] is a fundamental image enhancement technique utilized to adjust the brightness and contrast of images. This non-linear operation involves modifying pixel intensity values to compensate for the inherent nonlinear relationship between pixel values and light intensity in imaging devices. By applying a power-law function, gamma correction ensures that the displayed image appears more visually appealing and aligned with human perception. Gamma correction can be implemented using formula 1 or formula 2.

$$T(r) = r^{\gamma} \tag{1}$$

$$T(r) = \begin{cases} 0, & r < r_1 \\ (\frac{r - r_1}{r_2 - r_1})^{\gamma}, & r_1 \leq r \leq r_2 \\ 1, & r > r_2 \end{cases} \tag{2}$$

Figure 1 shows how this transformation function works.

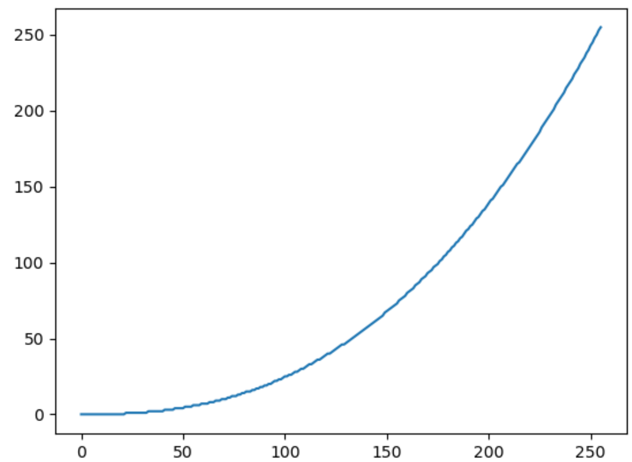

Figure 1: Gamma correction transformation function.

2.2.2 Logarithmic Correction

Logarithmic correction[5] is another image enhancement method that addresses issues related to the dynamic range of pixel intensities. This technique involves taking the logarithm of pixel values, leading to a compression of the intensity range. Logarithmic correction is particularly effective in enhancing details in darker regions of an image, making it a valuable tool for improving visibility and overall image quality. Figure 2 shows how this transformation function works.

Logarithmic correction can be implemented using formula 3.

$$T(r) = c \log_{10}(1 + r) \tag{3}$$

2.2.3 Inverse Logarithmic Correction

Inverse logarithmic correction, also known as anti-logarithmic correction, serves as a complementary technique to logarithmic correction. By applying the inverse of the logarithmic function to pixel values, this method expands the intensity range, particularly emphasizing details in brighter regions of an image. Inverse logarithmic correction proves useful in scenarios where enhancing

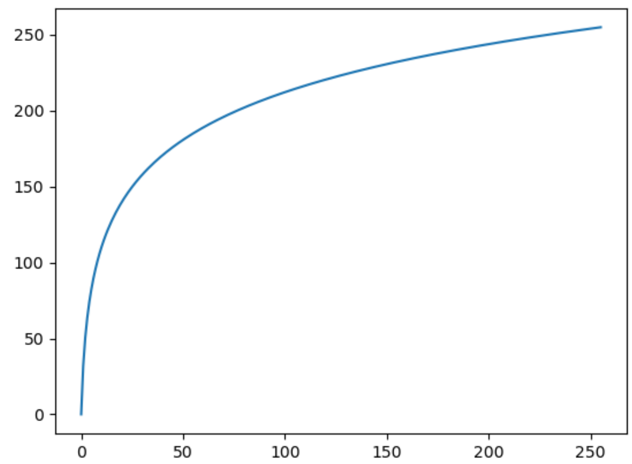

Figure 2: Log transformation function.

contrast in well-lit areas is crucial for visual interpretation. Figure 3 shows how this transformation function works.

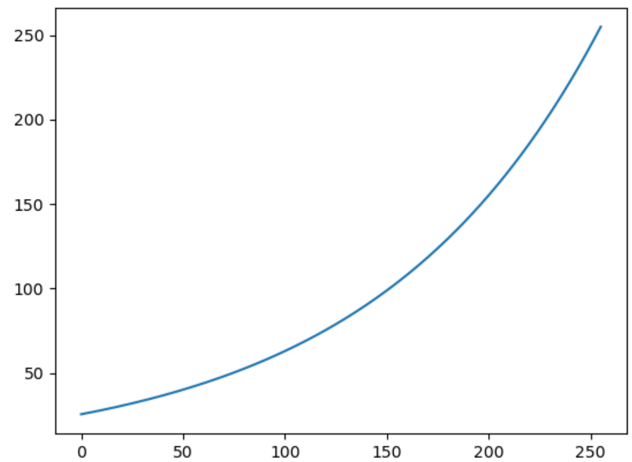

Figure 3: Inverse log transformation function.

Inverse logarithmic correction can be implemented using formula 4.

$$T(r) = 10^r \tag{4}$$

2.2.4 Histogram Equalization

Histogram equalization[6] is a prominent image enhancement technique that operates on the principle of redistributing pixel intensities to achieve a more uniform histogram, ultimately enhancing the overall contrast of an image. The primary objective is to address issues associated with unevenly distributed pixel intensities in an image, as such non-uniform distributions can lead to poor visibility of certain details and structures.

In the histogram equalization process, the cumulative distribution function (CDF) plays a crucial role. The CDF represents the cumulative probability of pixel intensities in the image, providing a comprehensive view of the distribution. By leveraging the CDF, histogram equalization transforms the pixel intensities in a way that maps them to a more evenly distributed range.

The algorithm works by computing the histogram of the original image, which illustrates the frequency of occurrence for each pixel intensity. Subsequently, the cumulative distribution function is derived from this histogram. The CDF is then normalized to scale its values to the dynamic range of pixel intensities. The final step involves mapping the original pixel intensities to their corresponding values in the normalized CDF.

Through this mapping process, histogram equalization effectively redistributes pixel intensities, emphasizing areas with lower frequency and de-emphasizing those with higher frequency. The result is a transformed image with improved contrast, revealing previously obscured details and structures. This technique is particularly advantageous in scenarios where the original image exhibits significant variations in pixel intensities, leading to a visually enhanced representation that is more visually appealing and informative.

2.3 Affine Transformations

Affine transformations[7] play a crucial role in image processing, preserving parallel lines and distances between points. This section examines two significant types of affine transformations: translation and rotation.

2.3.1 Translation

Translation[8], a fundamental affine transformation, shifts the position of an image by a specified distance along the x and/or y axes. Mathematically, the transformation matrix for 2D translation is represented as:

$$T_{translation} = \begin{bmatrix} 1 & 0 & \triangle x \\ 0 & 1 & \triangle y \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

Here, $\triangle x$ and $\triangle y$ denote the translation distances in the x and y directions, respectively. This transformation is applied to each pixel in the image, effectively relocating the entire image in the desired direction.

2.3.2 Rotation

Rotation[8], another essential affine transformation, entails rotating an image by a specified angle around a chosen center. The 2D rotation matrix is expressed as:

$$T_{rotation} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

Here, θ signifies the rotation angle in radians. The application of this transformation to each pixel in the image results in a rotated version of the original image.

3 EXPERIMENTAL RESULTS

3.1 Q1: Compare Zooming Methods

In Figure 4, a small image is presented, subject to examination using three distinct zooming methods. Figure 5 illustrates the zooming operations conducted on the original small image employing pixel replication, zero-order hold, and bilinear interpolation, each at a zoom factor of 2. The same methods underwent examination at a zoom factor of 4; however, owing to constraints imposed by page space limitations, the results are not presented in this context. Nonetheless, these results can be found in the associated Jupyter notebook.

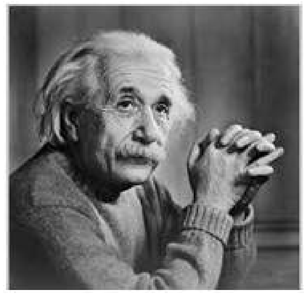

Figure 4: Original image.

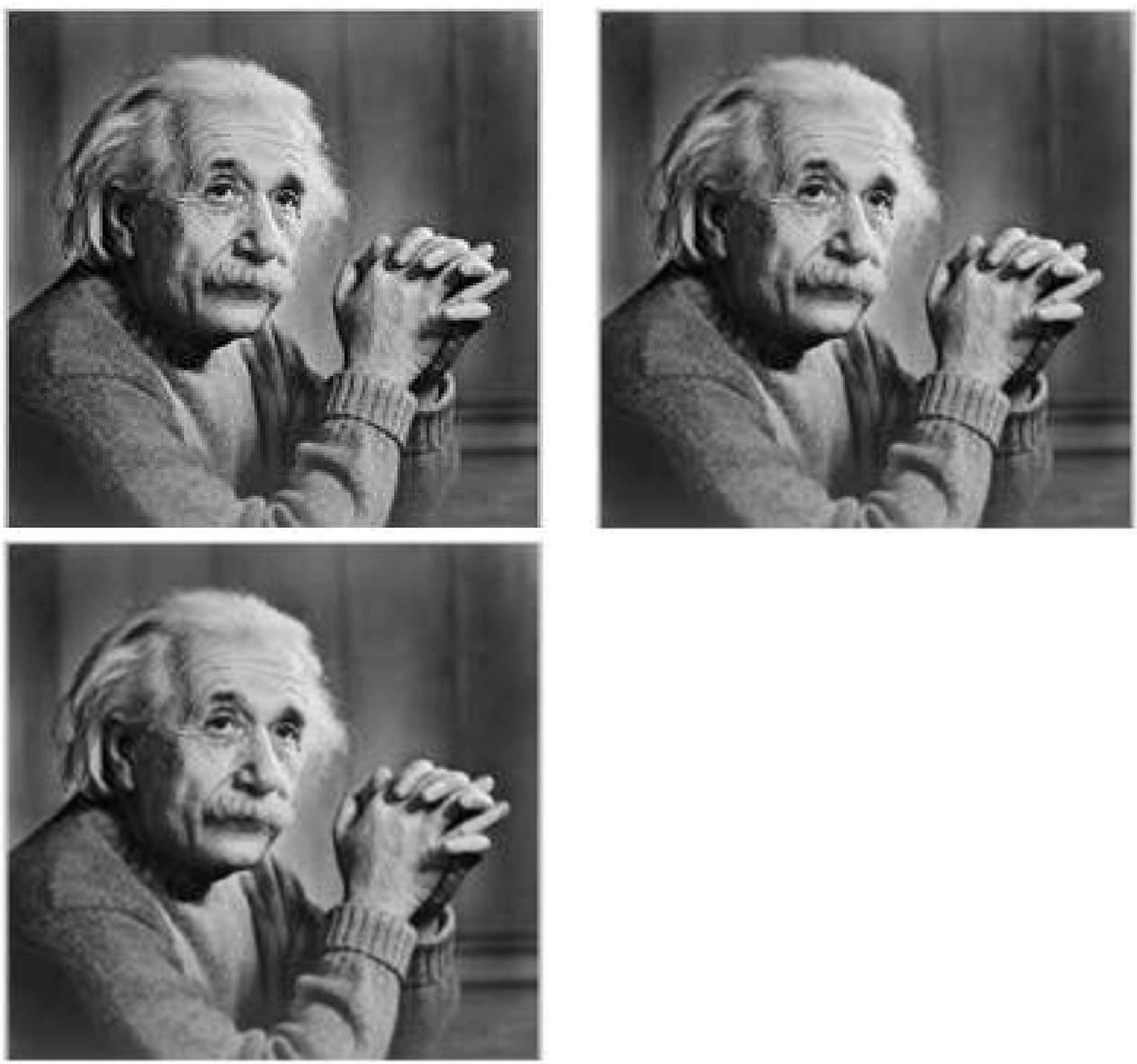

Figure 5: Pixel replication, zero-order hold, and bilinear interpolation, respectively (zoom factor=2).

3.2 Q2: Compare Contrast Enhancement methods

In Figure 6, the original image is juxtaposed with several transformations thereof. It is discernible that the application of logarithmic correction resulted in an increased brightness of the image. However, a preference for diminishing the overall brightness arises, as the current luminosity is deemed excessive. Both gamma correction and inverse logarithmic correction have demonstrated superior efficacy in achieving the desired outcome by enhancing the image's contrast.

Figure 6: Original, gamma corrected, logarithmic corrected, and inverse logarithmic corrected, respectively.

In Figure 7, histograms depicting the original image and its various transformations are presented. It is evident from the original image's histogram that its pixel values fall within the range of 100 to 255, indicating an overall brightness. The histograms of the gamma-corrected and inverse logarithmic-corrected images reveal a broader pixel value range, extending from 25 to 255 in gamma correction and from 0 to 220 in inverse logarithmic correction. Conversely, the histogram of the logarithmic-corrected image illustrates an increased brightness, compressing pixel values within the range of 210 to 255.

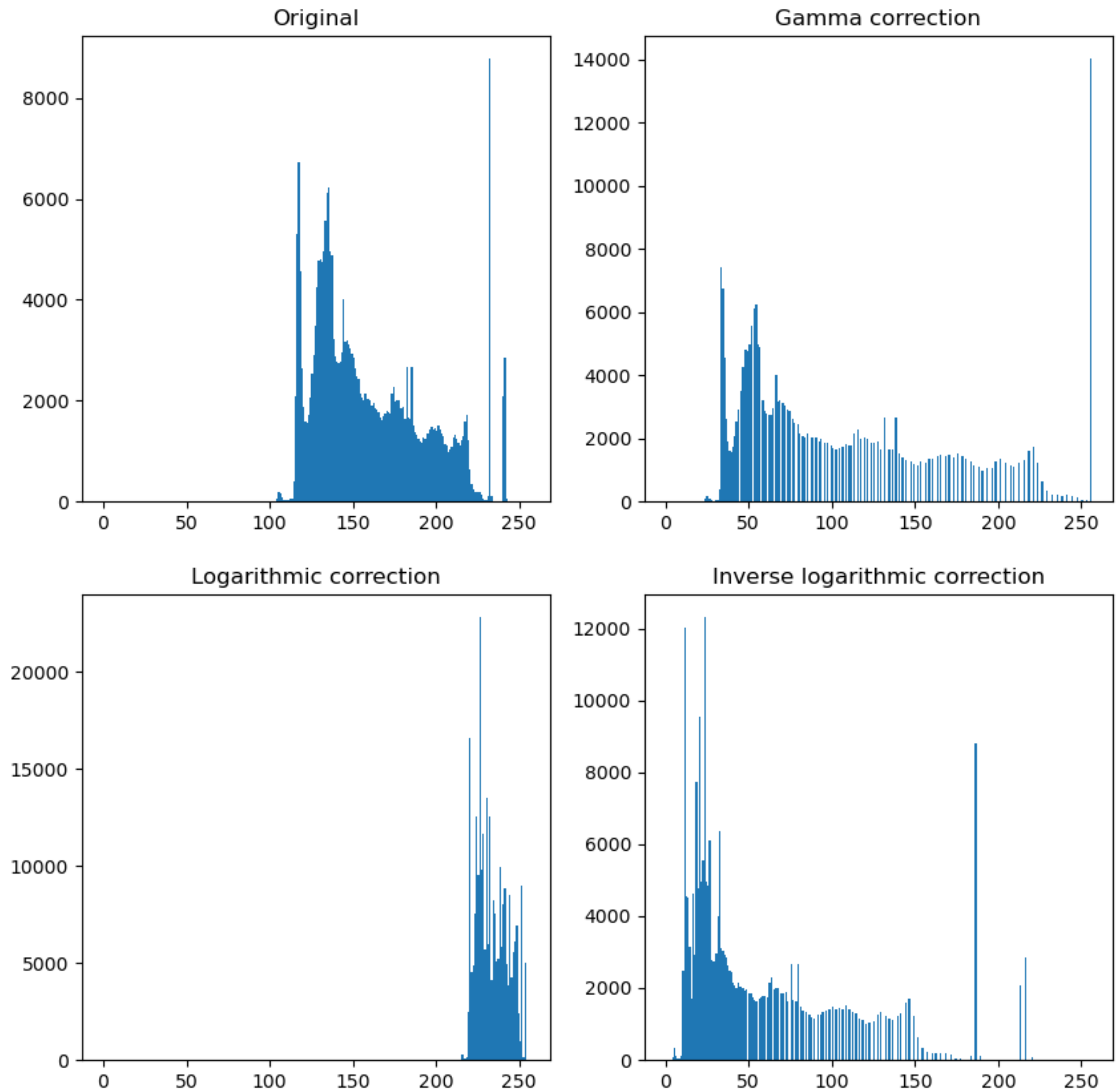

Figure 7: Original image and its transformations histograms

3.3 Q3: Analyzing the Histogram Equalization effect

In Figure 8, the original image is presented alongside its histogram-equalized counterpart. The enhanced contrast of the image is evident in the histogram-equalized version. Figure 9 illustrates the histograms of both images, elucidating that the right histogram is a redistribution of the left one, strategically executed to augment the image's contrast.

Figure 8: Original and histogram equalized images, respectively.

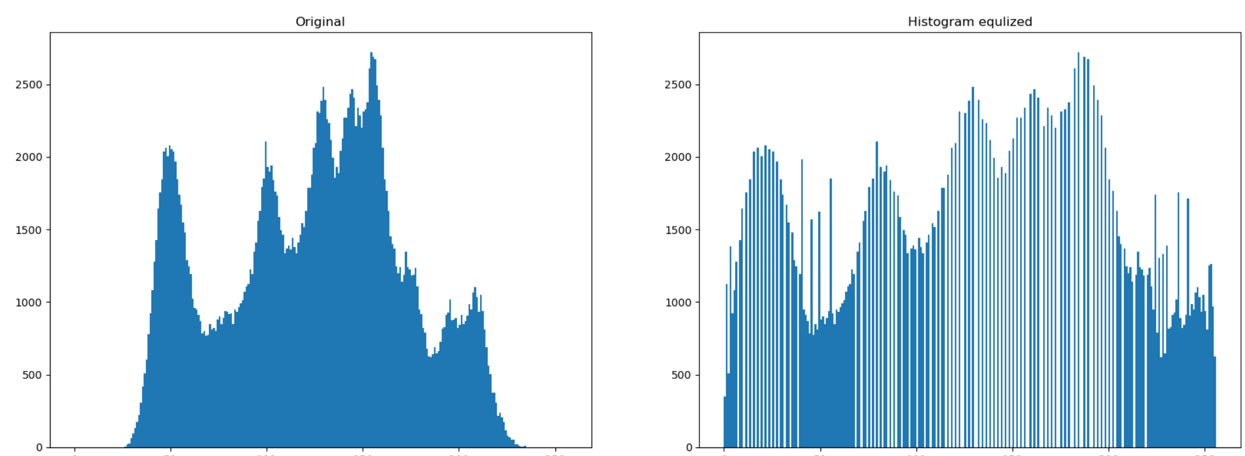

Figure 9: Histograms of original and histogram equalized images, respectively.

3.4 Q4: Translate and Rotate different objects in the same image

In Figure 10, the original and final images are presented. A small square undergoes a translation of 40 pixels in both directions, while a larger square experiences a counterclockwise rotation of 60 degrees. Affine transformation matrices were employed to execute these translation and rotation operations on the entire image. The operations were conducted individually on the original image, and subsequently, the segment containing the translated small square was concatenated with the segment harboring the rotated large square.

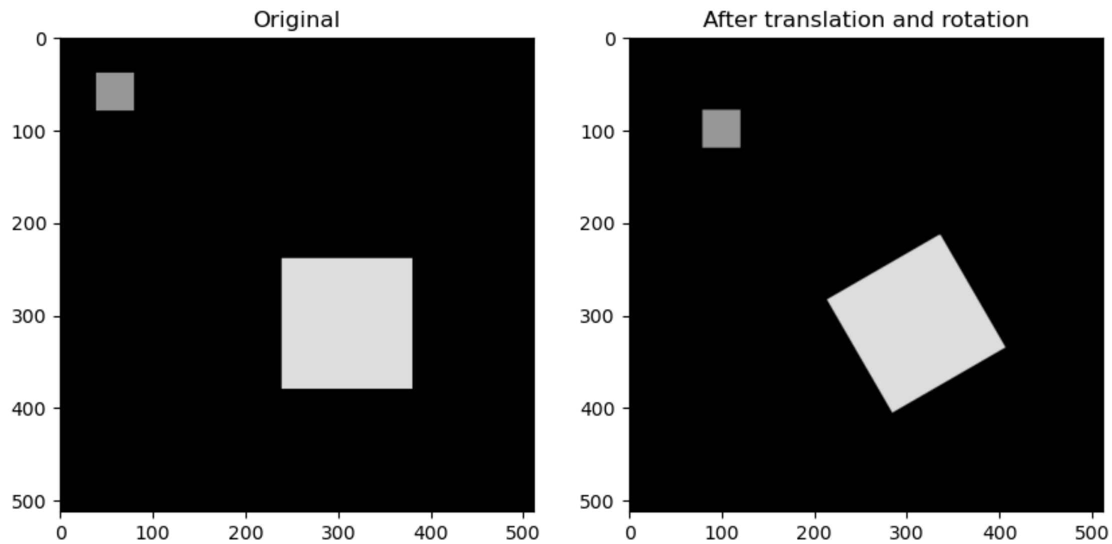

Figure 10: Original and final images, respectively.

3.5 Q5: Compare the effect of some transformation functions

In Figure 11, the original and transformed images are displayed. The ineffectiveness of the exponential transformation is evident in this context, as it results in darkening the image, contrary to the requirement of enhancing brightness in the skeleton part. Conversely, both the logarithmic and piecewise functions yield more favorable outcomes. The logarithmic function reveals not only the skeleton but also the muscles, whereas the piecewise function selectively enhances the brightness of the skeleton. Each of these transformations presents utility in distinct scenarios.

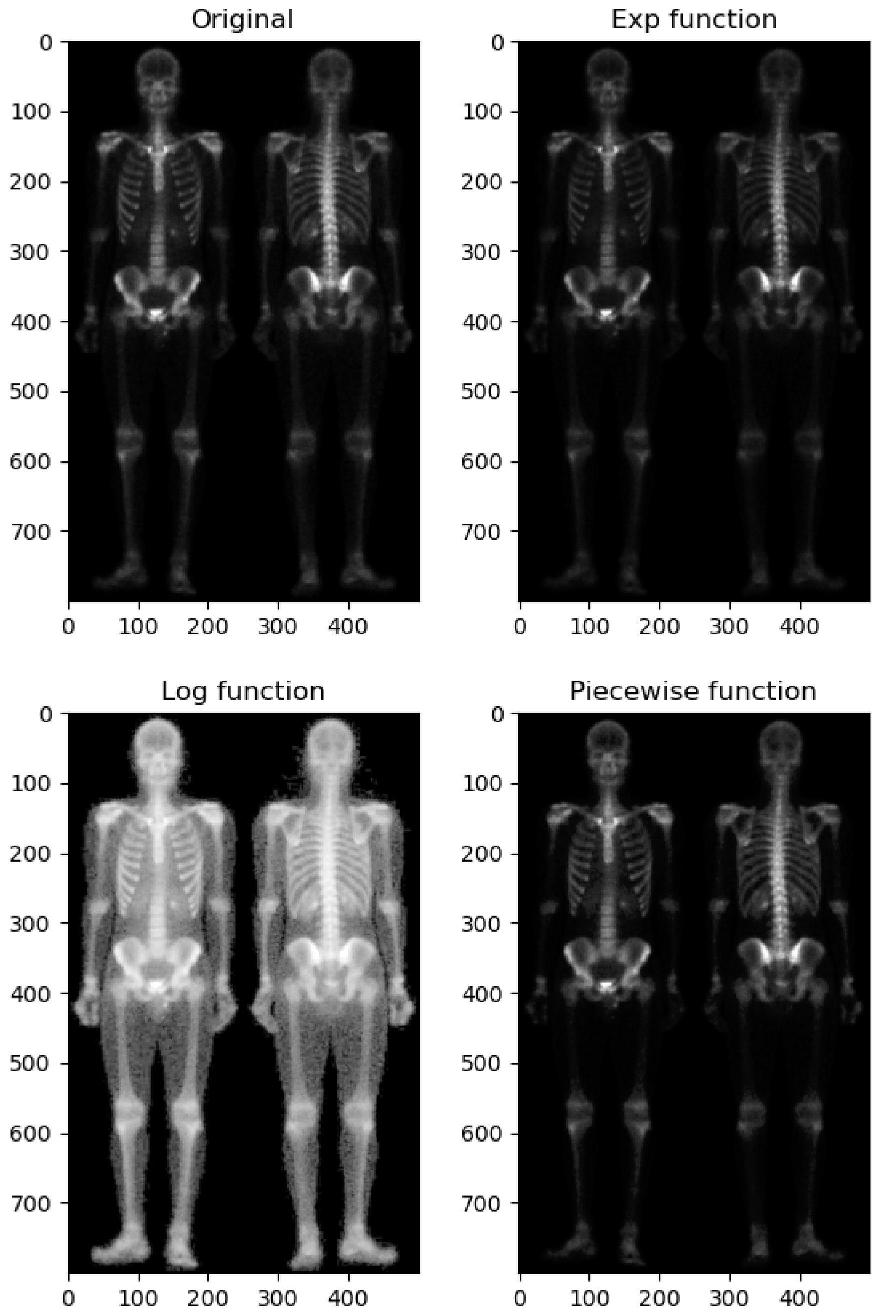

Figure 11: Original and transformed images.

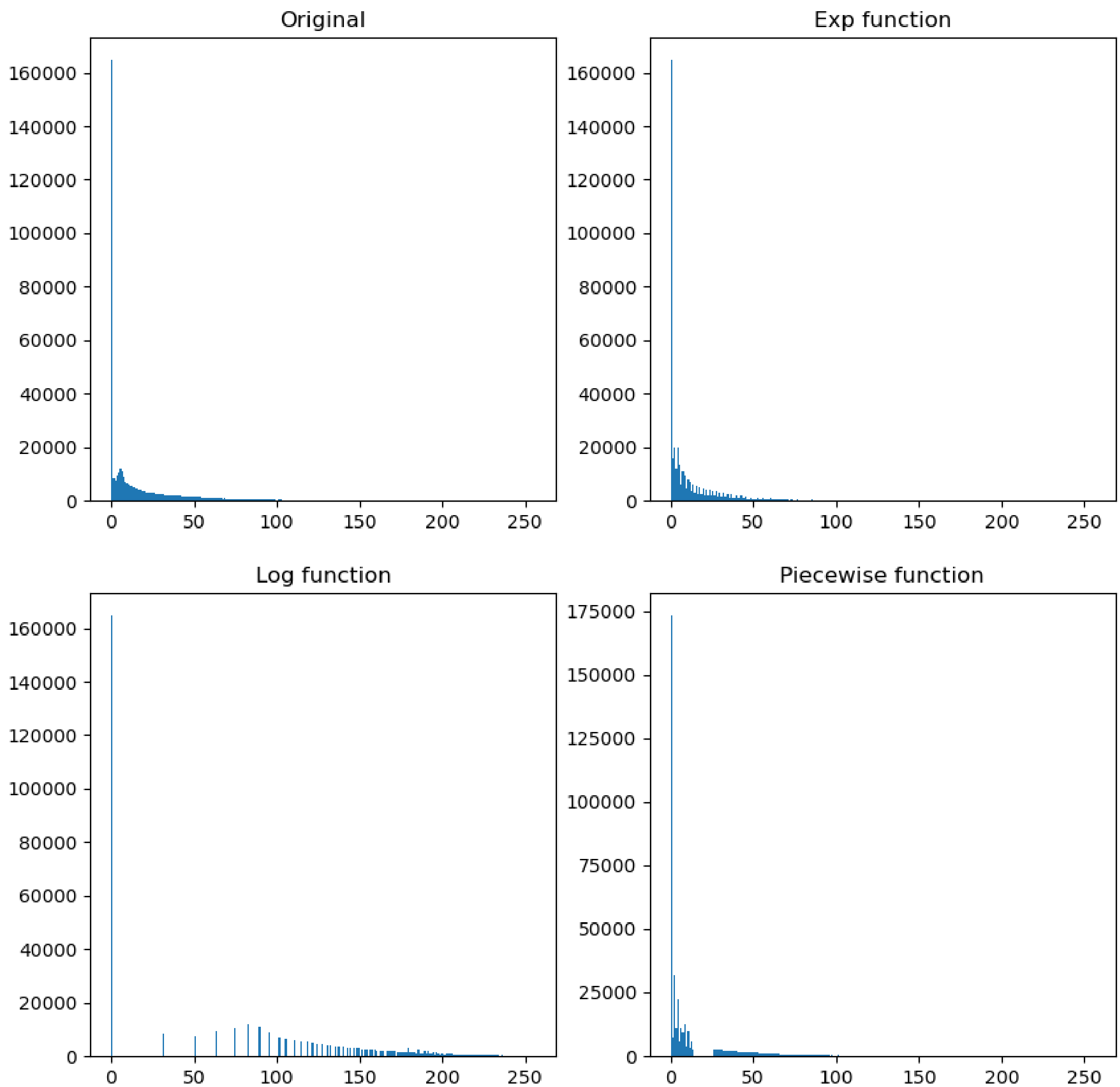

Figure 12: Histograms of original and transformed images.

4 CONCLUSION

In this project, an exploration of various image processing techniques unfolded, covering image zooming, enhancement, and affine transformations. The project delved into pixel replication, zero-order hold, and bilinear interpolation for image zooming, along with gamma correction, logarithmic correction, inverse logarithmic correction, and histogram equalization for image enhancement. Affine transformations, specifically translation and rotation, were also investigated.

The experimental results, as detailed in Section 3, provided insights into the effectiveness of these techniques. Key findings encompassed the comparative analysis of zooming methods (Q1), the evaluation of contrast enhancement methods (Q2), the examination of histogram equalization effects (Q3), and the exploration of translated and rotated objects within the same image (Q4). The project also scrutinized the impact of various transformation functions (Q5). These experimental outcomes elucidate the nuanced advantages and limitations of each technique, emphasizing their applicability in diverse scenarios. The project emphasizes the importance of method selection based on specific objectives and image characteristics.

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