Image Processing: Assignment #1

Problem 1 – Sampling, Quantization

a) The decision on how many megapixels a camera has, or how big the resolution is of a computer-generated image should lead to balance between image quality, performance and practical consideration.
When we think about steaming service, we want to get a good quality video (high resolution frames), but we need to consider limitation of the internet performance so that the streaming will smooth. Another example of quality - performance balance is in autonomous vehicles that use cameras for their operation. The image processing should be performed at a very fast pace, so the camera should have low resolution video, but not too low to avoid missing part of the feature in the frame.
We also need to consider the image size according to the hardware limitation, for example some systems with low amount of memory. The image size should be small, meaning with a low number of pixels.
In addition, physical related reasons are also should be taken into consideration. One important example is the size of camera sensor. The larger the sensor's surface area, it can gather more light in a single shot. Larger camera sensors are excellent for low-light photography. Although more megapixels creating a higher-resolution image with more details, trying to fit a lot of megapixels on a smaller sensor creates problems when it comes to low-light photography.

Some important aspects

- Sensor Size and Quality: Larger sensors can accommodate more megapixels without compromising image quality.
- Diffraction Limiting: At a certain point, increasing megapixels in a small sensor won't improve image quality due to diffraction limiting. This physical limitation means that after a certain density of pixels, adding more pixels doesn't necessarily improve image sharpness.
- Lens Quality: The quality of the lens must match the sensor's resolution.
- Processing Power: Higher resolution images demand more processing power for both capture and editing.
- Display Resolution: The resolution of displays (monitors, TVs, etc.) that will show the images is a consideration.
- Noise Performance: Higher megapixel counts on small sensors can lead to increased noise, especially in low light conditions, as each pixel receives less light.

b) Quantization is the second stage in the digitization process, in quantization stage, we choose number of gray levels according to number of assigned bits. The number of bits used to define each pixel is called BIT DEPTH. A lower bit depth means less possible color. Older computers had limited memory resources, so there should be a balance between the quality and the use of a memory for an image. Another consideration is the number of colors, old screens or other display gear can show, for example if a screen can display limited number of colors, there is no need for high bit depth (large number of bits to represent the pixel number)
To sum up, if we have a limited memory resources or less advanced screen, we need stronger quantization.

Some important aspects

- Color Depth: This refers to the number of bits used to represent the color of each pixel. Older computer hardware and less advanced screens had limited color depth due to technological constraints.

- Display Capabilities: Older or less advanced screens might not be able to display a wide range of colors or high-resolution images.

- File Size and Compression: Stronger quantization reduces the file size but can lead to loss of detail and image quality.

- Processing Power: The available processing power impacts how images are quantized. Older computers with limited CPU and GPU capabilities would struggle with high-resolution, minimally quantized images.

- Viewer Perception and Psychology: Human visual perception is more sensitive to certain colors and less to others. Quantization algorithms often take advantage of this, reducing precision in less sensitive color ranges to save data while maintaining perceived image quality.

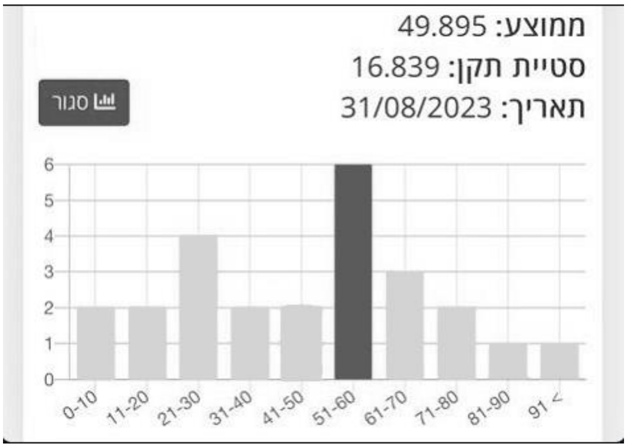
Problem 2 – Nyquist

a) $\sin(2\pi x)$ has a cycle in length 1. We saw in tutorial, for the sine wave $\sin(2\pi xk)$, for k>1 we shrink the wave, but for k<1 we stretch the wave. For $\sin(2\pi xk)\ with\ k = \frac{1}{2}$ we will get $\sin(\pi x)$ and its cycle in length 2 (stretched by a factor of 2). Thus $\sin(\pi xk)$ has wavelength in size $\frac{2}{k}$. Also, the value of A is not relevant because it defines the width of the sampled area in the sampling grid, and it's not relevant to the periodic image itself.

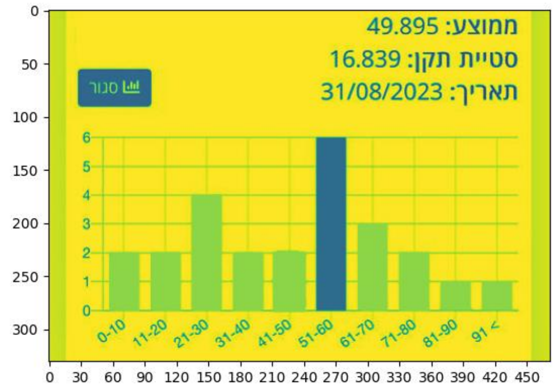
b) The wavelength of an image is $\frac{1}{frequency} \rightarrow frequency = \frac{1}{\text{wavelength}}$.
In this image $frequency_i = \frac{k}{2}$. According to Nyquist rule, to observe details at frequency f one must sample at frequency > 2f. Thus, the frequency of the sampling grid should be $frequency_{sgrid} > \frac{2k}{2} = k$. Therefore, k values should be lower than the sampling grid frequency.
Calculation of k for each value A = {0.25,2} and the distance unit is 1cm.
A=0.25: $frequency_{sgrid} = \frac{number\ of\ cycles}{distance\ unit} = \frac{2}{1} = 2 > k$
A=2: $frequency_{sgrid} = \frac{number\ of\ cycles}{distance\ unit} = \frac{\frac{1}{4}}{1} = \frac{1}{4} > k$

Problem 3 – Histograms, Matching, Quantization

a) The first image in gray scale.



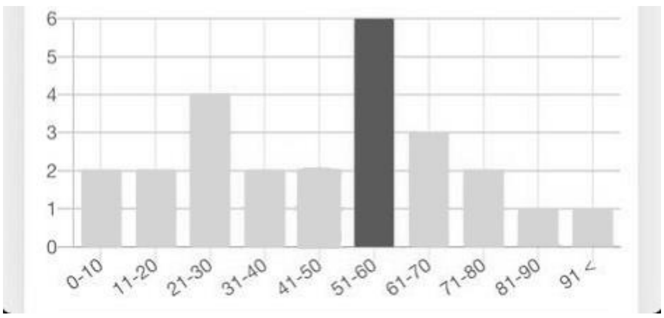
c) In compare histogram function we first calculate the cumulative histogram of the target (the number image) and then we create windows of all source image in shape of the target image.
By observing the first source image with matplotlib:



We cab see that the max bin height number is in the range of 25-56 on X axis and in range 100 to 141 on y axis, thus we choose to focus on this range in all images in order to optimize the runtime. In the loop of this range we calculate for each window the cumulative histogram. Afterwards we calculate the EMD by the sum of the absolute values of the cumulative histogram differences and return true if the current window has EMD lower than 260 with the range's cumulative histogram.

d) We put the call to the function 'compare_hist' on each image with the numbers in decreasing order, starting from 9 until 0. In a function 'recognize_topmost_number' , so we can call the function for each image.

e) By observing the lower part of the images in gray scale:



We need to distinguish between the bars and- grid+2 borders of the image (in same color), text and background. Thus, we choose the optimal number of gray levels to be 4 to distinguish between 4 ranges of gray. In order to separate between the bars pixels and the other we choose the threshold value to be 230.

<u>Output</u>

```
D:\venv\Image_Processing_labs\Scripts\pyt
Histogram a.jpg gave 2,2,4,2,2,6,3,2,1,1
Histogram b.jpg gave 6,2,1,1,3,3,6,2,2,3
Histogram c.jpg gave 0,0,0,0,0,0,1,1,1,1
Histogram d.jpg gave 1,0,2,3,4,3,5,5,6,2
Histogram e.jpg gave 2,1,1,3,2,5,1,1,2,3
Histogram f.jpg gave 1,0,1,1,1,4,1,1,2,1
Histogram g.jpg gave 1,1,1,3,1,2,9,3,3,0

Process finished with exit code 0
```