Image Processing - Exercise 2

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1.a Introduction

The goal of this assignment was to analyze and manipulate audio signals using various techniques such as **frequency truncation**, **spectrogram analysis**, and **signal processing**. The main tasks included adding watermarks to audio files, classifying them, and determining speedup methods. I used **Short-Time Fourier Transform (STFT)**, and the properties of audio frequency components, were utilized to solve these tasks. By analyzing the audio in both time and frequency domains, also hearing the track themselves, I was able to add, classify, and detect watermarks effectively.

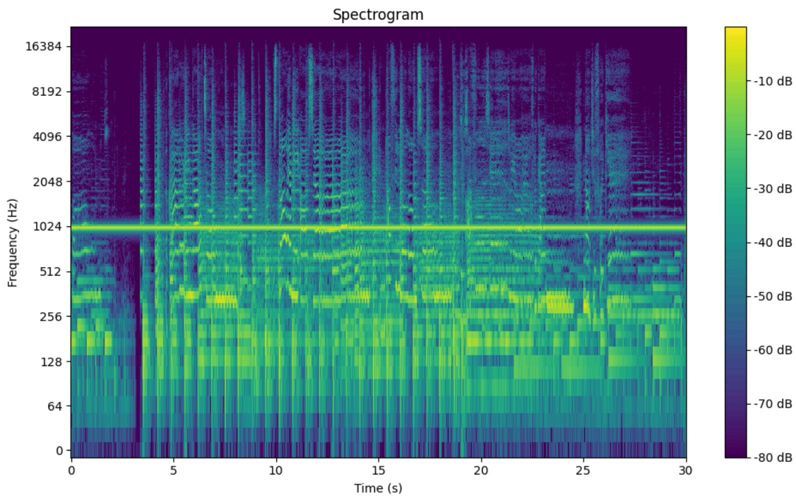
2.a-d Adding Watermarks

Since we learned that adult humans can sense frequencies between 0 and ~18000Hz

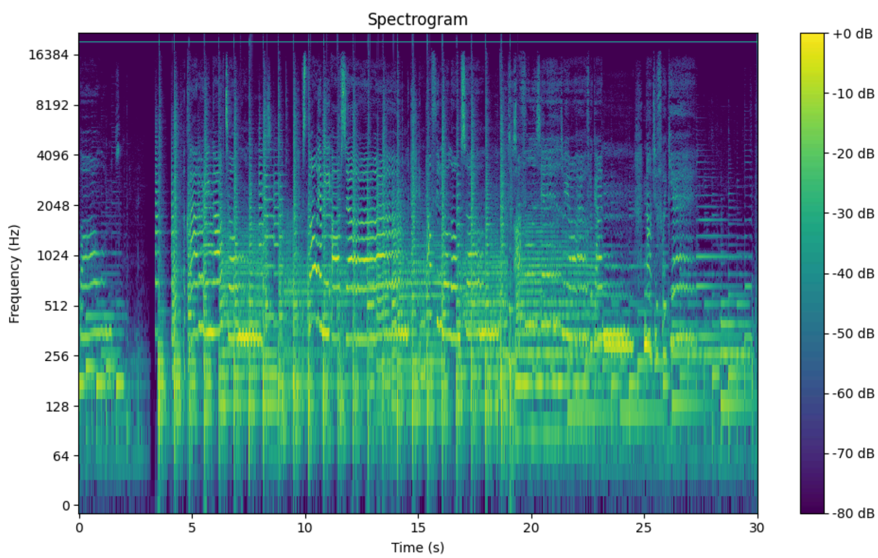
I created two tracks - one with a continues noises at 1000Hz, that is the watermarked “bad” audio that a listener can clearly tell its there, and the second file has a continues noise at 19500Hz, which I personally can’t tell its there, and according to what we learned in class its like that for most adult humans. A less successful method was to make a really quiet continues sound - which was barely seen in the histogram.

To verify the noise *is* there I plotted spectrograms for the two output files, and listened to the files.

Bad watermark audio spectogram



Good watermark audio spectogram



We can clearly see in the graph the watermarks described above (continues sounds at 1000Hz, 19500Hz accordingly).

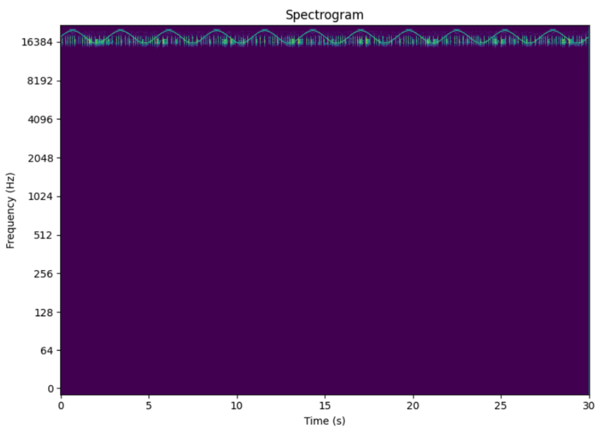
2.e Watermarks for images

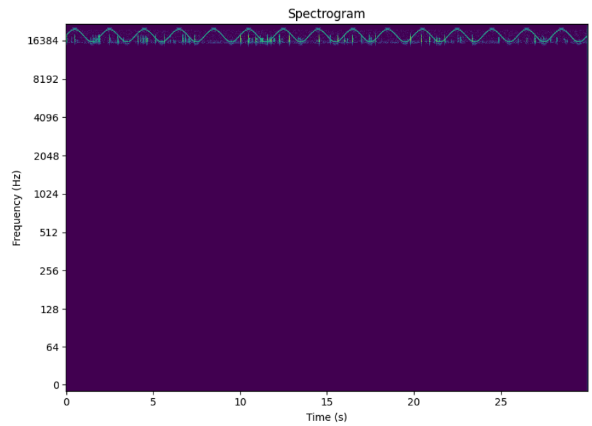
If I were to design a watermark for images, I would probably use Discrete Fourier Transform, to get from it the image in the signal domain. I would then mark dots in a known pattern at particular pixels in the higher frequencies. That would probably not make a noticeable difference in the image, yet still would be able to be recognized easily by an algorithm.

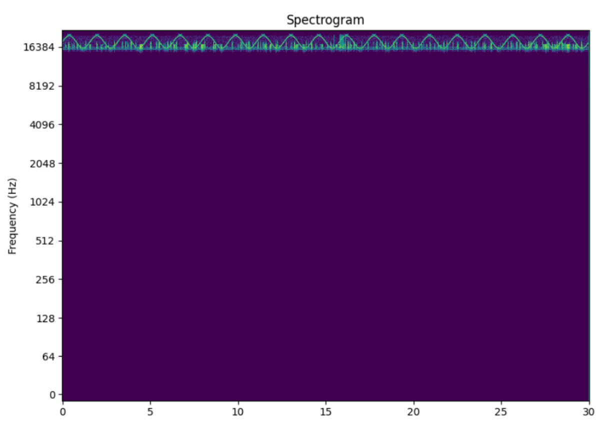
3.a-e Classifying watermarks

To classify the watermarked audio files, I used their (non log) spectrograms. Once I noticed in the spectrogram a sine function watermark at the highest frequencies (16000-20000) I truncated the files to have only frequencies in that range, to see the watermarks visually better.

The truncated graphs I used for the analysis: group 1-3 accordingly







To summarize: I could see that I can classify the files into 3 groups - all watermarked with one of 3 different sine functions. That being said, the solution itself is just hardcoded, reflecting my decision.

Group 1

Audio files 1,2,3.

The function is

$f(x) = 2000sin(\frac{11\pi}{15}x) + 18000$

Note: to calculate the exact sine equation I counted how many peaks we have in 30 seconds, that way I can calculate frequency, and amplitude. I just did some trial and error with the truncation, and discovered that the sines oscillate between 16000 and 20000.

Group 2

Audio files 4,5,6

$f(x) = 2000sin(\pi x) + 18000$

Group 3

Audio files 7,8,9

$f(x) = 2000sin(\frac{19\pi}{15}x) + 18000$

3.f Removing a watermark

To remove the watermark, one solution can be removing from the audio track the frequencies in which the watermark is.

Challenges include:

- Ensuring minimal loss of surrounding frequencies, or “crucial” frequencies which will make the sound stay the same for the average user.
- Avoiding artifacts due to frequency removal.

4. Determining speedup method

4.a - Speedup Methods

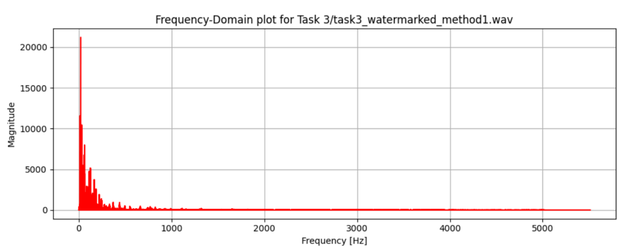
- **Time Domain**:
  - The signal is played back faster by skipping or downsampling samples.
  - **Perceptual Effect**: The pitch increases.
  - **Technical Effect**: The sampling rate changes accordingly to the speed up, audio duration shortens by the same factor.
- **Frequency Domain**:
  - The duration is reduced using techniques like **phase vocoding**.

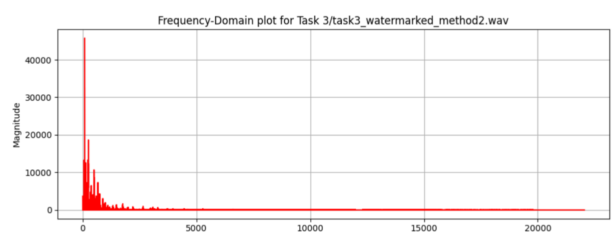
- **Perceptual Effect**: The pitch is preserved, but the audio still speeds up.
- **Technical Effect**: Sampling rate stays unchanged, and audio duration shortens by the same factor of speeding up.

4.b-c Identifying the Method

By analyzing the spectrograms and time-domain plots, and also considering the sampling rates of both files which I extracted using Python I discovered that

task3_watermarked_method1.wav sampling rate was 11025
task3_watermarked_method2.wav sampling rate was 44100
When listening to the audio tracks, I could tell that the original pitch of the track is the one of **method2.wav**. From what we learned in class, only a speedup / slowdown in the **signal domain** results in a change of pitch, so I was able to differentiate right away between the two. The differences between the sampling rate rest assured that statement, again according to what we saw in class[1].
The last evidence came from comparing the tracks frequency domain plots. We saw in the lecture that a speedup in the time domain will result in a lowered frequency. That is exactly what we can see in the plots - track method1.wav had lower frequencies than method2.wav





So I was able to conclude that:
task3_watermarked_method1.wav was sped up in the **signal domain.**
task3_watermarked_method2.wav was sped up in the **frequency domain**.
both was “sped up” by a factor of $x = 0.25$ (can be described also as slowed down by a factor of 4).

[1] Lecture 2 - Fourier 1D slides 44-47

Conclusion

In this assignment, I successfully analyzed, manipulated, and classified audio signals using concepts such as **Fourier Transform**, **spectrogram analysis**, and signal processing techniques. The following key insights and findings emerged:

1. Watermark Design and Analysis - I added “good” and “bad” watermarks to audio files. Both of which can be easily detected by a suitable algorithm.
2. Watermark Classification
   - I grouped the audio files into three classes by identifying watermark sine functions in the **16,000–20,000 Hz range** using frequency truncation and spectrograms.
   - By counting waveform peaks and visually analyzing spectrograms, I extracted and approximated the sine functions embedded in each group. The results were consistent and reflected the periodic behavior of the watermarks.
3. Speedup Detection
   - I distinguished between time-domain and frequency-domain speedup methods by analyzing sampling rates, spectrograms, and frequency-domain plots:
   - Both methods resulted in a speedup factor of **x = 0.25** (or a slowdown by a factor of 4).