In the Name of God

Signals and Systems

Project Phase 2

Spring Semester 1403-04
Department of Electrical Engineering

Sharif University of Technology
Instructor: Dr. B. Khalaj

Due Date: 1404/04/13

Important Notes

1. Feel free to reach out with any questions about the project via Telegram or by emailing me at Gmail.

2. Please submit your project in the form of a single ZIP file containing all the necessary files. The file should be named GroupXX.zip where XX is your group number.

3. Groups should be formed with a maximum of two students.

4. The project carries a total of 100 points. Bonus points, marked with (∗), will be added to your final score. The maximum score for each question is also provided.

1 Project Description and Theoretical Questions

1.1 Introduction to License Plate Recognition (LPR)

In the real world, license plate recognition (LPR) systems are essential tools used in traffic monitoring, access control, and law enforcement. These systems rely on a series of signal and image processing techniques to extract the characters from license plates and identify them correctly. In this phase of the project, you will build a simplified yet practically-inspired LPR system using fundamental concepts from image processing and signals.

The core method you will employ for character recognition is correlation. The correlation process compares segments of the license plate image with a set of reference characters to find the best match.

However, real-world LPR systems face several challenges such as image blurring due to motion or focus, low sampling rates from limited hardware, or noisy imaging conditions. We simulate some of these challenges in this project to understand their effects on signal integrity and recognition accuracy.

First, we will review and examine a few prerequisite topics for the project.

1.1.1 Two-Dimensional Correlation

In this project, you will perform character recognition using correlation. Although correlation is a technique traditionally used for comparing one-dimensional signals, it can also be adapted for image processing tasks such as template matching.

Your goal is to investigate how this one-dimensional correlation method can be used to compare images or parts of images (e.g., character segments). This approach is at the heart of the recognition method used in this project.

1.1.1 Questions

1. What is the mathematical definition of correlation between two signals? Explain it in your own words and write the standard formula. What does the correlation value represent? (5)
2. Research and explain how a method designed for one-dimensional signals can be used to compare images or image segments. Describe your proposed approach clearly. (Do not explain 2D correlation.) (2.5)

1.1.2 Image Blurring and Degradation Modeling

Blurring in images often results from motion, out-of-focus lenses, or deliberate smoothing filters. In signal processing terms, this can be modeled as the output of a system applied to an image. For example:

$$H_{\text{blur}}(z) = \frac{1-p}{1-pz^{-1}}$$

This is a recursive 1D IIR filter (Infinite Impulse Response), often used for exponential smoothing or blurring.

1.1.2 Questions

1. Explain how this 1D filter is applied to images, and also explain the parameter *p* and its effect on the filter's performance. (5)
2. If we assume that we have the blur transformation function (blur kernel) of the channel, can we recover a high-quality and clean image? Why? (2.5)

1.1.3 Sampling Rate and Resolution Effects

In image processing, sampling corresponds to the image resolution. Reducing the resolution is equivalent to downsampling the image, which affects the frequency content and the ability to extract fine details such as the shape of characters. If sampling is too coarse, important features may be lost. In this project, we test how much the resolution can be reduced while still enabling character recognition via correlation.

1.1.3 Questions

1. Do a bit of research on 2D sampling theory and briefly summarize your understanding.(5)

2 Implementation

You are provided with a set of license plate images. Your task is to develop a character recognition system that can extract and identify the letters and digits from the plates. For simplicity, assume that the system provides you with all license plates without any change in orientation or angle. Two folders named "numbers" and "letters" have been provided to you. Note that the letters and digits appearing on the license plates are limited to the samples in these folders.

The implementation must be done in two main scenarios:

2.1 Ideal Case – Controlled Environment

In this scenario, you are expected to process clean and undistorted plate images where all characters are clearly visible. You may assume the following simplifications:

- The resolution is sufficient for accurate character segmentation.
- There is minimal or no noise and blur.

In the "ideal" folder, license plates are provided for you that are only related to this section.

2.2 Realistic Case – Simulated Real-World Conditions

In this part, you will work with blurred versions of the same license plates. These images simulate realistic degradation caused by optical imperfections or motion blur. However, you are not given the exact blur kernel. Your goal is to analyze and reverse the degradation effects as far as possible.

In the "realistic" folder, license plates are provided for you that are only related to this section.

Ideal Case :

1) Write a function that takes a license plate image as input and split the image into its individual characters (both digits and letters). Plot each segmented character. (10)
2) Now, using the provided technique, recognize each character and print the final license plate as output. Make sure to report the correlation value obtained for character recognition.(Do this for all the license plates in "ideal" folder.) (15)
3) In this step, analyze the effect of spatial downsampling (i.e., resolution reduction) on character recognition accuracy. (10)
   - Apply downsampling to the license plate image before performing character segmentation and also plot before and after.
   - Repeat the character segmentation and recognition process for multiple downsampling rates (e.g., 1/2, 1/4, 1/6, ...).
   - For each rate, evaluate whether the characters are still recognizable using your correlation-based method.
   - Determine and report the minimum sampling rate at which the license plate is still correctly recognizable.
   - Plot or tabulate your findings to show how recognition accuracy changes with sampling rate.
   - It is not necessary to include all the processes for all the license plates in "ideal" folder **in the report**. Therefore, include the processing steps for one license plate image in the report, and only report the final outputs for the remaining license plates.

Realistic Case :

In this section, you will work with blurred license plate images that simulate real-world optical degradation (e.g., motion blur, defocus). As discussed earlier, such blurring can be modeled as the output of a linear system applied to the original image.

In this experiment, the blurring process is modeled using a system with transfer function

$$H_{\text{blur}}(z) = \frac{1-p}{1-pz^{-1}}$$

where the function structure is given, but the parameter p is unknown.

1) Attempt to extract the license plate characters using the functions from the previous section. Evaluate whether character recognition is successful without any deblurring.
2) Since your answer to the previous section is likely negative, you should now use the available information to extract higher-quality and higher-resolution images. Estimate the optimal value of p and use it to find deblur filter. (10)
3) The blur in the provided license plate images is modeled using a one-dimensional linear filter. As discussed earlier, such filters can be applied to two-dimensional images in horizontal and vertical directions. Apply the filter you obtained in the previous section (with the estimated optimal parameter p) to deblur the image. Plot and save the deblurred images. Select the clearest version for further processing. (10)

4) Pass the deblurred image to the character recognition function that you implemented in the ideal section. Observe whether the segmented characters are recognizable using the correlation-based method. If the characters are not correctly identified, or the correlation scores are significantly low, Re-examine your deblurring filter design. Adjust the blur parameter p, the direction of filtering, or the method of inverse filtering. Repeat the deblurring and recognition process until satisfactory results are obtained. (Do this for all the license plates in "realistic" folder) (15)
5) In this step, analyze the effect of spatial downsampling (i.e., resolution reduction) on character recognition accuracy. (10)
   - Apply downsampling to the license plate image before performing character segmentation and also plot before and after.
   - Repeat the character segmentation and recognition process for multiple downsampling rates (e.g., 1/2, 1/4, 1/6, ...).
   - For each rate, evaluate whether the characters are still recognizable using your correlation-based method.
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6) (*) In "noisy" folder, there are 2 noisy license plate images. You are asked to determine, without writing any new code (using only existing functions and code), which of these images contains higher-frequency noise content. Provide a convincing justification for your answer.(5)

You have to write a full report of your implementation. (Same as phase1)

Put the code files, output images, output text and the report, screenshots of the plots in proper folders in the ZIP file. The report should be in PDF format and named Report.pdf. The code files should be in a folder named Code and etc. There is (5) bonus points for commenting the code properly and orderliness of the files as requested.