Lecture "Digital Signal Processing"

Prof. Dr. Dietrich Klakow, Summer Term 2021

Project

Submission deadline: 10 August 2021, 23:59

Submission Instructions:

- You are required to hand in your solutions in a group of two students.
- Project solution with Python should be submitted as an ipynb file (Jupyter Notebook or Google Colab), where every function is written in a separate block.
- Submission should be done via Microsoft Teams by one of the group members.
- Submission should be named as: Project_matriculationnumber1_matriculationnumber2.zip

The submission should contain the following files:

- Project Reports (one report for each problem)
- code and supporting files (e.g. result output, etc.)
- file "README" that contains an information on all team members:
  name, matriculation number, and email address.

General Guidelines for Implementation:

The code should be well structured and commented. Quality of the software / implementation being readable, well structured, and documented will be one of the grading criteria.

The allowed Python libraries to use include numpy, math, matplotlib.pyplot, soundfile for reading the audio file, librosa for features extraction and plotting (task 1.1), and pandas for data frame. Matlab libraries would be the equivalent ones.

In general, any other libraries are not allowed unless they are mentioned in specific tasks. If you have the need to use other essential libraries that are not mentioned, feel free to consult with the tutors and we will assess your request.

1 BIC-based Audio Segmentation

In many audio processing tasks, automatic audio segmentation and clustering are essential to tackle the problem of acoustic change detection, i.e. the detection of speaker, channel, and environment changes in a continuous audio stream. The segmentation of continuous audio is useful as a preprocessing activity for further clustering of the segments that eventually can be used for speaker identification, noise rejection, etc.

When the input audio stream is modeled as a Gaussian process in the cepstral space, a maximum likelihood approach can be used to to detect turns of a Gaussian process, and the decision of a turn is based on the Bayesian Information Criterion (BIC) [1]. In other words, the BIC procedure is to choose the model for which the BIC criterion is maximized.

1.1 (5P) Features Extraction

1. Prior to performing the audio segmentation, perform the standard 24-dimensional MFCC feature extraction on the input audio file *Interview.wav*, with frame width 25ms and frame shift 10ms, to form the data samples, and plot the results.

2. To further enrich the features collection, add at least another 3 features of your choice, and plot the results. Why do you choose those features?

1.2 (10P) Segmentation using BIC

1. Implement an automatic audio segmentation using BIC based on the Section 3 of this paper [2], where the basic of BIC is explained in Section 2. Note that the objective is to identify all possible frames where there is a segment boundary. In other words, audio segmentation aims at splitting an audio stream into acoustically homogeneous segments. Thus, the output of this implementation should be audio segments of the input audio file that each segment contains only one homogeneous sound.

   As starting point, the window size of the data samples $\{\mathbf{x}_1, ..., \mathbf{x}_n\}$ can be set to 100 frames, which can then be increased accordingly (if no segment boundary is found) as explained in section 3.2.1 and 3.2.2 of the reference paper [2]. The penalty weight can first be set to 1, and modified to other values, if necessary, to improve the segmentation result.

2. Discuss the rationale behind your choice for the values of the parameters.

Note that if you need to do PCA to improve your segmentation result, you are allowed to use the Python sklearn library or the equivalent Matlab library.

1.3 (10P) Report Writing

Write an academic report summarizing the activities you have done above in not more than 5 pages (excluding references). The report should contain clear sections of introduction, background information, experimental procedure or implementation details including justification on why certain approaches and/or parameters values are selected, results and discussion, and lastly conclusion.

Note that the grading criteria include the structure of the report, results quality, depth of the insights, and appropriate citations.

2 Tracking $\mathcal{R}$ of COVID-19 using Kalman Filter

Epidemics have been some of the most destructive events in human history and therefore the subject of Epidemiology has been developed to model the behaviour of diseases and the steps that can be taken to control their impact to the population. Experts have then developed SIR (Susceptible, Infectious, Recovered) model that can more accurately represents how an infection would spread through a population by taking into consideration that some people will recover from the disease and no longer be susceptible. Additionally, they have come up with parameters such as the Effective Reproduction Number $\mathcal{R}$, which is defined as the average number of secondary cases produced by a primary case. This means that the number of the infected individuals increases as long as $\mathcal{R} > 1$.

In the latest case of epidemic and pandemic of COVID-19, we are interested in tracking its $\mathcal{R}$ to help all stakeholders involved in the pandemic management to know which actions that work more effectively in suppressing the spread of the disease. And based on the SIR model, $\mathcal{R}$ is linearly related to the growth rate of the number of infected individuals.

2.1 (10P) $\mathcal{R}$ Estimation with Kalman Filter

1. Based on the approach and equations described in this paper [3], show how to derive equation [2] from the earlier equations given in the paper.

2. Compute the time-series growth rate of the infected individuals from the provided time-series input data (i.e. cumulative confirmed cases in Germany *DE_Confirmed.csv*) based on the equations provided in the reference paper [3].

3. Use the time-series data to estimate the required σ_ϵ based on the method presented in this paper [4], with the filter's window size of your choice. This means that you should first implement a median filter to filter your time-series data.

4. From the result of task 2 and task 3, and based on equation [5] of the main reference paper [3], estimate $\mathcal{R}$ using Kalman filter and plot its time-series starting from the given initial and end dates. Use $\sigma_\eta = 50\%$ of σ_ϵ. What can you say about the result?

5. Modify your parameter as such that you can produce a smoother estimation of $\mathcal{R}$. What is the rationale behind your selected modification?

6. What can you say about the state-space dynamics that is used in the paper? Can it adequately represent the reality? Why or why not?

The following details can be used for the implementation of task 2.1:

- Use $\frac{1}{\gamma} = 7$ days, where γ is the transition rate from infected to recovered.

- The initial growth rate of the infected individuals can be assumed to be drawn from a distribution of $\mathcal{N}(0.25, 0.15^2)$. From this value, the initial $\mathcal{R}$ for the estimation can then be computed. For the sake of result reproducibility, use the random seed = 12345.
- Time-series input data on the cumulative confirmed cases in Germany [5] is provided with this Project sheet. As shown in the header, the initial date is 01.03.2020 and the end date is 30.06.2021.
- If required, the time-series data on cumulative number of dead and recovered individuals [5] is also provided together with this Project sheet (*DE_Dead.csv* and *DE_Recovered.csv*).
- If required, assume the population of Germany in 2020 is 83.16 millions [6].

2.2 (5P) Predicting future $\mathcal{R}$

1. Propose and implement a method to predict the $\mathcal{R}$ and its variance for the next 7 days when the observed data is not available. Plot your result together with the previous result of task 2.1.
2. Why do you select your method?

(*An example method called Nowcasting with its detailed paper [7] can be one of your inspiration sources. DeepL Translator may come handy for non-German speakers.*)

2.3 (10P) Report Writing

Write an academic report summarizing the activities you have done above including the answers and justifications requested in tasks 2.1 and 2.2 in not more than 5 pages (excluding References). The same requirements of section 1.3 apply.

References

[1] S. S. Chen, P. S. Gopalakrishnan, "Speaker, Environment and Channel Change Detection and Clustering via the Bayesian Information Criterion," 1998, pp. 127–132.

[2] A. Tritschler, R. Gopinath, "Improved Speaker Segmentation and Segments Clustering Using the Bayesian Information Criterion," 6th European Conference onSpeech Communication and Technology, Budapest, 1999.

[3] F.A. Marioli, F. Bullano, S. Kucinskas, C.R.Moreno, "Tracking $\mathcal{R}$ of COVID-19: A new real-time estimation using the Kalman filter," PLOS ONE, 2021.

[4] J. Peksinski, G. Mikolajczak, "Estimation of the noise variance in time series using a median filter," Computer Applications in Electrical Engineering, 2014.

[5] John Hopkins University, Center for Systems Science and Engineering (CSSE), "CSSEGISandData/COVID-19," accessed on: 02.07.2021.

[6] Statista, "Germany: Total population from 2016 to 2026," accessed on: 29.06.2021.

[7] Robert Koch-Institut, "Erläuterung der Schätzung der zeitlich variierenden Reproduktionszahl R," 2020.