ENEE630 Advanced Digital Signal Processing

Project 2: Linear Prediction and Spectrum Estimation

The grade of the project will be based on the completeness, performance, and novelty of your design as well as the quality of your report. Your project report should consist of introduction, design and simulation, and results and discussions. You should prepare a README file (in txt or html) to describe your files for source codes, audio results, and report, and follow the submission guideline posted on the course webpage.

You may use MATLAB or other programming languages (e.g. C/C++) to do your project. For MATLAB built-in signal processing functions, you are only allowed to use the primitive ones (such as convolution, FFT, etc.). You should implement your own functions to estimate autocorrelation function, realize Levinson-Durbin recursion, and do auto-regression, etc. You are not allowed to use or modify upon any speech encoder/decoder built by other people (such as those in the Internet and textbook CDs). Any references used in your work should be properly acknowledged in your report.

You will work in a two-student team. The same instructions as Project 1 on teamwork and guidance on write-up apply. Each student should sign the **Honor Pledge** at the beginning of the report: "*I pledge in my honor that I have not given or received any unauthorized assistance on this report*".

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1. **Analyzing Speech Signals**: This task lets you explore the basic analysis and synthesis of speech signal based on the concept of linear prediction. Some test clips are provided in course webpage, encoded at 8kHz and 8bit per sample.

(1) Design an experiment to determine the average duration of the speech signal within which the signal is approximately (wide-sense) stationary. We shall call this duration "frame length". You can partition the speech signal into frames of this length.

(2) Build a 10^{th}-order linear predictive model and implement a function that can efficiently find the optimal prediction coefficients for a given frame of the speech signal. Show through simulation how much difference between the true speech signal and the predicted one from your model. Note that you can use different coefficients for different frames, and you should examine the difference both "objectively" (using some suitable quantitative measures) and "subjectively" (listen to the signals).

(3) Examine variations on the above speech analysis: through simulations of higher and lower order than 10, discuss how the selection of order affects the performance of the prediction.

Bonus points: you are encouraged to explore lattice structures when building the analysis and synthesis parts of linear prediction.

2. **Linear Prediction Codec**: So far you have built tools to determine the model coefficients and the prediction error ("residue"). As there are just a few coefficients for each frame of a speech signal and the dynamic range of the residue is small, you can use fewer bits to represent and transmit the speech signal than keeping the raw samples at a fixed rate of 8 bits/sample. Develop a coding scheme, which should determine when you need to update and transmit the model coefficients, how the transmitter

can inform the receiver of this model update, how you encode the parameters and the residues, and other things you find necessary. Write the output of your encoder as a bitstream to a file, which will be read by your decoder to reconstruct the speech. Justify the choices you have made in your design. Determine the compression ratio of the best result your codec on test clips can have in terms of some good performance index (which may take account of sound quality, waveform distortion, etc).

`Note: You should conduct your exploration and implementation in a systematic way: start with the simple choices (such as a simple quantizer and encoding, etc.), devise approaches to validate your design as well as each implementation step/module, and gradually refine your work.`

3. **Warm-up on Spectrum Estimation**: As a first step, you are asked to write functions to generate five random processes. Each of them is generated using some model as explained below and then corrupted by white noise for about 25dB of signal-to-noise ratio (SNR). The first process uses an autoregressive (AR) model; the second process uses a moving average (MA) model; the third uses an ARMA model; the fourth contains several sinusoids at different frequencies; and the fifth contains the sum of two sinusoids and an AR process. The input argument of your function specifies the SNR as well as the order and parameters of the processes to be generated. Derive the expression of the Power Spectrum Density (P.S.D.) for each process, and use computer to plot this "ground-truth" P.S.D.

4. **Exploration of Spectrum Estimation Methods:** Apply spectrum estimation methods from the lectures and readings to the random processes from Task-1, and examine the estimated spectrum by each method. You should include 2-3 representative techniques each from parametric approaches (AR/MA/ARMA and subspace) and non-parametric approaches.

   For this task, you are allowed to use MATLAB built-in functions or other library functions (as well as the functions you developed in the above linear prediction tasks), but you must acknowledge the source of these functions that are not solely developed by you or are adapted by you. We strongly encourage you to implement your own as this helps you develop first-hand and deeper understandings, and compare/verify the results from your implementation with the built-in/library ones.

   You can choose a few reasonable sets of parameters for each type of process (e.g., AR/MA of order 3~10). Consider the cases of having a short record (say, 32 to 64 samples) versus having a long record (say, a thousand samples) available to you to do the spectrum estimation. Compare the results by different methods and also with the true P.S.D. How good is each estimation approach? Under what situation does it give good or bad estimation? Discuss your findings.

5. **Spectrum Estimation on Real-World Data:** On the course website, we provide you a few files of real-world measurements that have been decimated to 1000Hz. The signal spectrum composition varies over time, although it can be reasonably assume that at a short time window the signal is approximately wide sense stationary and may contain dominant energy around some frequencies. Apply the spectrum estimation methods that you have examined above to analyze the spectrum of these data. Make an estimate of the dominant frequency below 100Hz for each time window you have, denoted as f[n]. Overlap in the window is allowed, and you should determine the amount of overlap.

   For several files specified on the website, please examine the pairwise correlation coefficients of the f[n] that you obtained for these files, and try this at different alignment shifts. Discuss your findings.

6. **(Bonus Task) Linear Prediction of Stock Market Data**: The MATLAB file DJIAdata.mat on the course webpage contains a sequence of Dow Jones Industrial Average (DJIA) weekly closing prices over a 94-year period (1897-1990). With such a long sequence, the linear prediction method can be designed based on one section of the data (i.e. the "training part") and then tested over other sections to evaluate its effectiveness as a predictor (i.e. the "testing part"). Performance of the method on this real data set may also reveal some limitations of the linear prediction method by its inherent assumption that the data are stationary and fit an all-pole model.

   Use your linear predictor to examine the DJIA data. You may want to evaluate the performance of different prediction orders. Examine when your predictor is doing a good job and when is not (especially in the realistic prediction situation where your training and testing data are different, e.g. use the first decade data to design the predictor and apply it on later decades). Then develop different predictors, one optimized for each decade, and compare them to see how different the prediction coefficients are. Discuss your findings.

`Note: Your linear prediction analysis does not have to limit to the raw stock data itself. Does the short-term average value stay constant or have a upward/downward trend? How would the values vary from such averages? How would the relative change behave?`

Resources and suggestions on technical and write-up for your project

- Make sure you <u>explain and analyze</u> your results: What do they tell us? What conclusion can we draw? ... Critical evaluations and discussions are keys to a good technical report. Don't just put figure/table and move on. Make sure you label the axes of your figures, and provide self-explanatory legend for multiple curves.

- When you print out figures, try to avoid using dark background when possible – it won't show up well and it consumes lots of ink. Also please use double-sided printing for your report when possible.

- Submit early - don't wait for the last minute in uploading. There could be unexpected hassle - so plan ahead! Late submission/upload will not be accepted! Please print out your hard copy in double-sided way when possible.

Resources and suggestions on team work

- Teamwork capability is an important skill to succeed in today's R&D workforce, and in many occasions one will need to work with people whom he/she may not know before. You will be teamed up with a randomly assigned partner to carry out this project.

- A teamwork evaluation form is given to you at the start of the project with an intention to help you examine and improve your teamwork. It is to be best interest of each of you that you as a team communicate and work together in an open and collegial way. At the end of your project, please fill out this evaluation form. You are strongly encouraged to provide comments, especially to explain the situations you encountered in the team work and how you and your teammates handled the situations.

- It is common to have one person to lead a task, but as part of the education process, all persons in your team should participate the discussions and when needed, help out the implementation, validation, and write-up. Take a systematic approach to tackle a big task – for example, divide the task into small subtasks, conquer them, and integrate. Start your project early, set milestones, review your progress, and adjust your plan as needed. While we will enforce a "no-free ride" policy, you should also recognize that we all have different strength and weaknesses – when your partner has difficulty to get things done, you need to lend a hand and act toward the ultimate goal of delivering a good project.

(For this project, both team members should contribute substantially to linear prediction and spectrum estimation tasks.)

- Grading: Your grade will be based on the quality of the project you deliver. In the event that one person contributes substantially less than the other one, the grade will be adjusted accordingly. We will enforce this "no-free ride" policy and free-rider will receive a low grade. The main contributor in this situation may receive a higher grade, provided that he/she has made a good effort in resolving the issues in the collaboration.

- A list of teamwork capabilities and the associated characteristics can be found at: http://www.personal.psu.edu/faculty/d/x/dxm12/angel/ist331sp02/peer_assessmnent.htm