ENEE 630 Project 1: Filterbank, Subband Coding, and Wavelets

The grade of the project will be based on the completeness, performance, and critical analysis of your design as well as the quality of your report. Your project report on Task 1-4 should consist of introduction, design, simulation results and discussions; assessment on Task 5 will be announced in class.

You should prepare a README file (in txt or html) to describe your files for source codes, image 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, and you should write your own codes. Any references used in your work and any material that are not made solely by you (including but not limited to figures, plots, diagrams, etc.) should be properly acknowledged in your report.

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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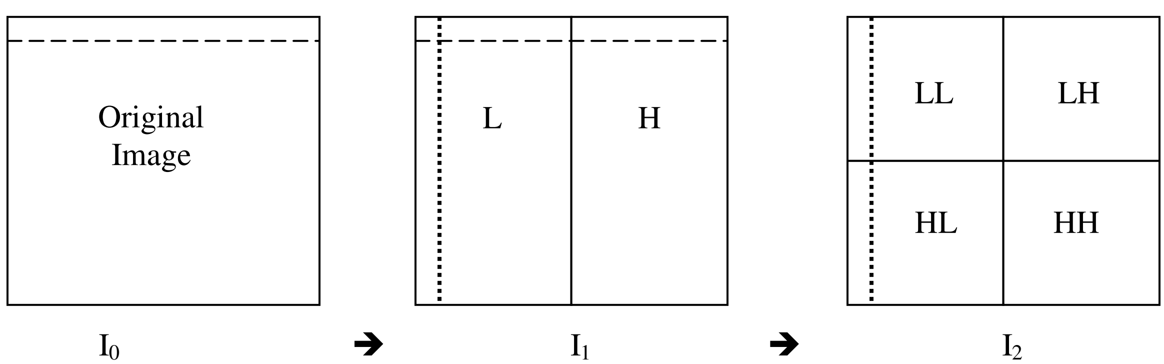
1. Design a perfect reconstruction QMF bank with a simple choice of analysis filters H1(z) = H0(-z). Show the forms of H0(z), H1(z), F0(z), and F1(z) that will make the filter bank perfect reconstruction. Implement the filter bank and demonstrate through simulation that your QMF bank is a perfect reconstruction system. Discuss the advantages and disadvantages of such design, supported by your simulations.

2. Subject to the constraint of linear-phase FIR filter H0(z), design a QMF bank that is capable of offering good response of LPF H0(z) and HPF H1(z) and in the mean time making the reconstruction as perfect as possible. Demonstrate through simulations how good your design is. Will you be able to achieve perfect reconstruction? Why or why not? Discuss and compare the pros and cons of this design with the one in Task-1.

3. The filter bank for processing 1-D signal can be extended to processing 2-D signal (such as digital image). We first apply the 2-channel analysis filterbank to each row of an image I_0. We generate an intermediate image I_1 so that the first half of each row is the decimated low-frequency subband signal for the corresponding row of the original image, and the second half is the high-frequency one. We then apply the 2-channel analysis filterbank again, but this time to each column of the intermediate image I_1. We put together a final image I_2, where each column has the first half to be a low-frequency subband signal and the second half to be a high-frequency one. I_2 consists of four subband "images", namely, LL, LH, HL, and HH (where HL indicates low frequency along horizontal direction and high along vertical direction; other notations are similarly defined).



After one round of subband decomposition, each subband can be further decomposed into four as needed and thus building a 2-D tree-based filter bank. After subband decomposition, the subbands may have different dynamic range. This allows you to use a different number of bits per value to represent the subbands, and hopefully by a good design of filter bank and quantizers, you can represent the original image in good quality with fewer average bits per pixel than the typical 8 bits/pixel for a grayscale image.

Consider the use of a simple N-level uniform quantizer to encode a subband signal with ceil($\log_2 N$) bits. The dynamic range of a sub-band signal sometimes may be quite large, but most values are in a small range. In this case, determine what range should be used by the quantizer and clip off the value out of this range to achieve a good tradeoff between signal compression and fidelity. The number of bits and the dynamic range chosen for your uniform quantizer should be properly chosen and can be different from subband to subband.

Use the filters that you have designed so far to perform subband coding on images. Determine which subbands to further decompose and which not to, and illustrate the final structure of your filter bank. Show how few bits you can use to encode the image without significant perceivable distortion. Develop a meaningful performance index to measure the distortion. Discuss how your choices of the filters, the filter bank structure, and the total decomposition levels impact the coding performance.

<u>Further explorations</u>: After examining the performances with uniform quantizers, you are encouraged to explore the other quantizers and encoding techniques. Bonus points will be rewarded for well carried out implementations, comparisons, and discussions.

4. **BONUS – Aliasing Contest:** Aliasing is a common artifacts associated with signal sampling at an insufficient rate. Common visual examples of aliasing include the zig-zag edge on a supposedly smooth boundary at a diagonal direction, the formation of "Moiré Pattern" associated with scanning a hardcopy newspaper/magazine picture, and a seemingly backward turning wheel of a vehicle captured by video camera. Construct, demonstrate, and analyze your own example for aliasing effects associated with multirate signal processing. Bonus points will be given to creative and illustrative work.

   Related suggestion: you may find it helpful to examine the intermediate aliasing effect at various stages in your QMF bank to gain some intuitive insights and reinforce the concepts learnt in class.

5. **Learning More through Self-Study:** A signature of graduate education is to pave way for you to learn how to acquire new knowledge independently and think on your own feet. This task is to give you a feel of using what you have learned as a foundation and explore related knowledge that is new to you. Each student will be assessed on this task <u>individually</u>, although reading group is allowed and discussions are encouraged during the self-study stage.

   - **Wavelet:** As some of you may be aware of, wavelet is one of the most popular words in the technical literature of the 1990s. Theories on wavelets, filter banks, and multiresolution signal analysis were initially developed rather independently in the fields of applied mathematics, signal processing, and computer vision, respectively, and later have converged and generated interests with a wide range of applications. Based on the multirate theories and techniques you have learned, you are asked to acquire knowledge about the basic principles and results on wavelets through self-study. Pay attention to the relation and connections between filter banks and wavelets, and the relation between wavelet and Fourier transforms.

- **Compressive sensing:** We have discussed extensively that for a discrete-time signal that is bandlimited (i.e. the support of the signal spectrum is finite and well within the period of 2π), we can retain fewer samples without losing information to recover the original signal perfectly. The bandlimitness implies that there are certain constraints and relationship among the signal samples in the time domain (and equivalently, the Fourier coefficients in the spectral domain). What if a signal's spectrum support is very wide due to non-zero coefficients scattered along a subset of frequencies over a wide frequency range? How to utilize such sparsity and provide most efficient sampling and processing, also known as compressive sensing, has received active attentions from the signal processing and applied mathematics community in recent years. Based on the multirate theories and techniques you have learned, you are asked to acquire knowledge about the basic principles and results on compressive sensing through self-study.

A list of suggested readings on these topics will be posted on the course webpage. We will also provide you a brief introduction and a fairly high-level overview in class. You should take good notes as you carry out the reading and learning. This task will be assessed through an open-notes quiz in the November time frame (details will be discussed in class). The quiz will cover and assess the basics on wavelet and compressive sensing, extended from the multirate material that you have learned in Part 1 of this course.

References and Suggestions:

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

▪ The course website has a helpful document that provides a quick review and warm-up exercises on using MATLAB, e.g. to do I/O operations and simple processing on image files.

▪ Provide quantitative way to check P.R. and other properties alike in addition to plot the input/output. E.g. derive the I/O response using your filter coefficients and demonstrate the P.R.; measure the difference, etc.

▪ 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.

▪ Show image in the correct aspect ratio. When you print out images/figures, try to avoid using dark background when possible -- it won't show up well and it consumes lots of ink.

▪ 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. Note <u>both</u> team members should contribute <u>substantially</u> to Task#3 and Task#4. 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.

- 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, <u>provided that</u> 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