A Presentation on

Subband Coding Of Images

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Introduction

- Subband coding is a popular method for source coding of images.
  It is the next step after Transform coding.
- One drawback of transform coding is the artificial division of source image into blocks.
- One approach in avoiding this is to split the image into different frequency bands without imposing any artificial block structure.
- After the image has been decomposed into its constituents, coding technique best suited to each constituent can be used.
- Also each constituent can have different perceptual characteristics, that can be exploited while quantization.

A Simple Example

- Consider the following sequence, say Xn :

  10 14 10 12 14 8 14 12 10 8 10 12

- Since there is significant sample-to-sample correlation, we can use a DPCM scheme for compressing the sequence. Sample-to-sample differences :

  10 4 -4 2 2 -6 6 -2 -2 -2 2 2

- Dynamic range of the above sequence (ignoring the first element) = 6-(-6) = 12.
- If the quantizer uses M levels of reconstruction then step size Δ = 12/M.
- Hence maximum quantization error = $\Delta/2$ = 6/M.

- Now suppose we define two sequences

$$Y_n = 0.5(X_n + X_{n-1}) \text{ and } Z_n = 0.5(X_n - X_{n-1}).$$

A Simple Example

- The sequence Yn can be produced as :

  10 12 12 11 13 11 11 13 11 10 9 11

- Since there is significant sample-to-sample correlation, we can use a DPCM scheme for compressing the sequence. Sample-to-sample differences :

  10 2 0 -1 2 -2 0 2 -2 -1 -1 2

- Dynamic range of the above sequence (ignoring the first element) = 2-(-2) = 4.
- Step size Δ = 4/M and maximum quantization error = Δ/2 = 2/M.

- Sequence Zn can be calculated as :

  0 2 -2 1 1 -3 3 -1 -1 -1 1 1

A Simple Example

- The sample-to-sample difference varies more than the actual values. Hence Differential encoding is not a proper choice. Instead each sample can be quantized independently.

- Dynamic range of the sequence = 3-(-3) = 6.
- Step size Δ = 6/M and maximum quantization error = $\Delta/2$ = 3/M.

- Hence for same number of bits per sample, we can code both Y_n and Z_n and incur less distortion. At the reconstruction side, Y_n and Z_n can be added to get X_n. The maximum possible quantization error = 2/M + 3/M = 5/M which is less then 6/M which would occur if the sequence X_n is directly encoded.

- Moreover, it is easy to see that $X_{2n} = Y_{2n} + Z_{2n}$ and $X_{2n-1} = Y_{2n} - Z_{2n}$.
- Hence entire X_n can be regenerated by using only the even samples (alternate samples) of Z_n and Y_n.

A Simple Example : Conclusions

- The number of different values transmitted are the same, whether we transmit Xn or Yn and Zn.
- The two subsequences have different characteristics, which led to usage of different techniques to encode them.
- If Xn were not spiltted, we would have been essentially using the same approach to compress both sequences.
- We could extend the method by decomposing the subsequences further.

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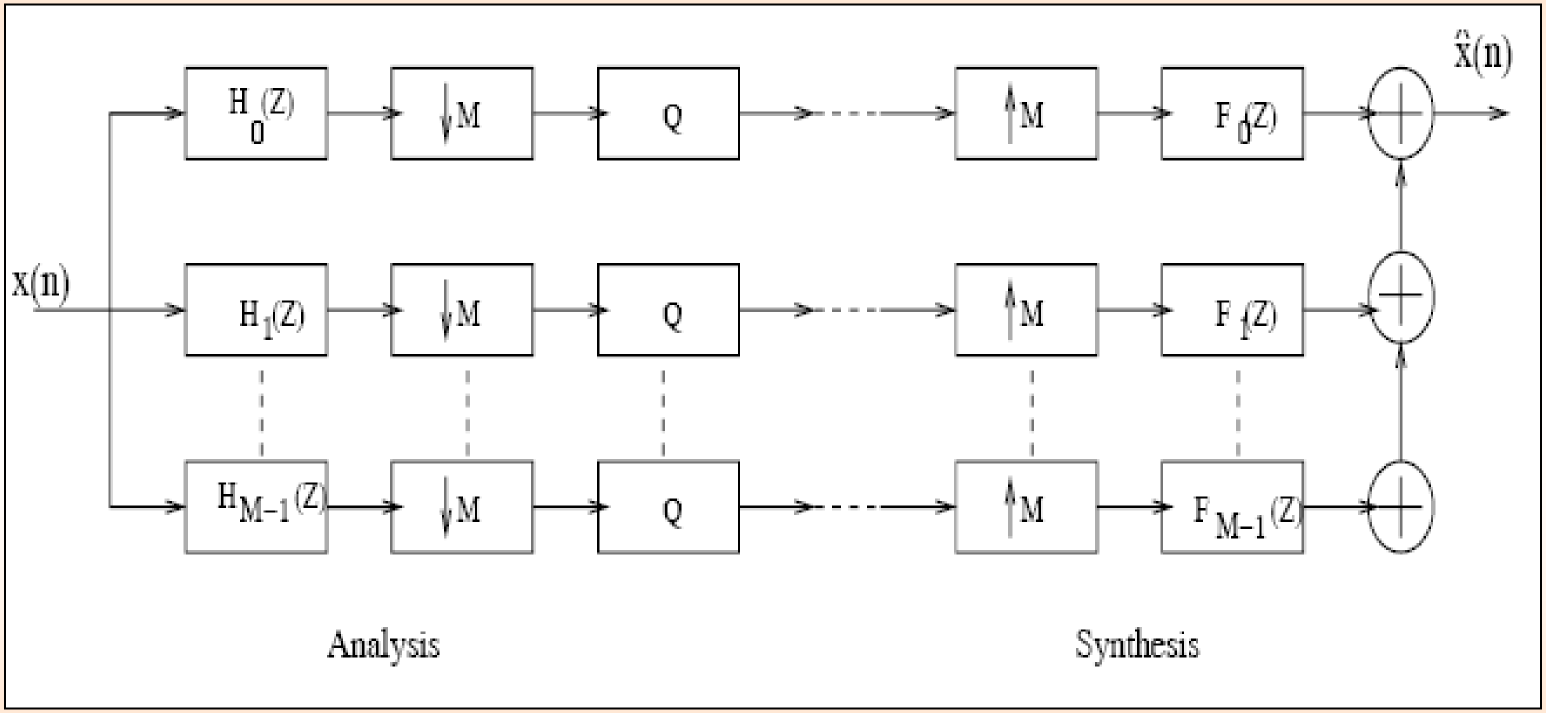
Subband Coding

- The basic Subband Coding system Consists of three major components

    # Analysis Filter bank
    # Quantization and coding
    # Synthesis Filter bank

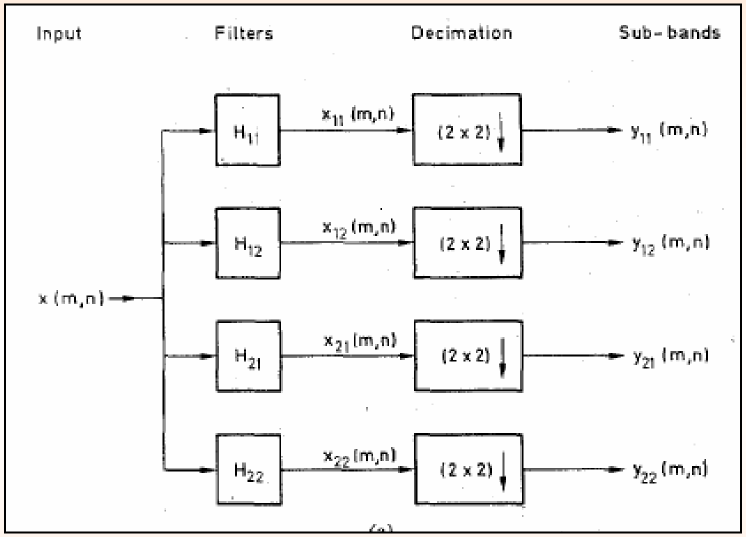
- In analysis stage, the source output (image) is passed through a bank of filters, called the analysis filter bank, which cover the range of frequencies that make up the source output.
- The passbands of the filters can be overlapping or non-overlapping.
- The output of the filters are then sub-sampled or decimated in accordance with Nyquist rule.

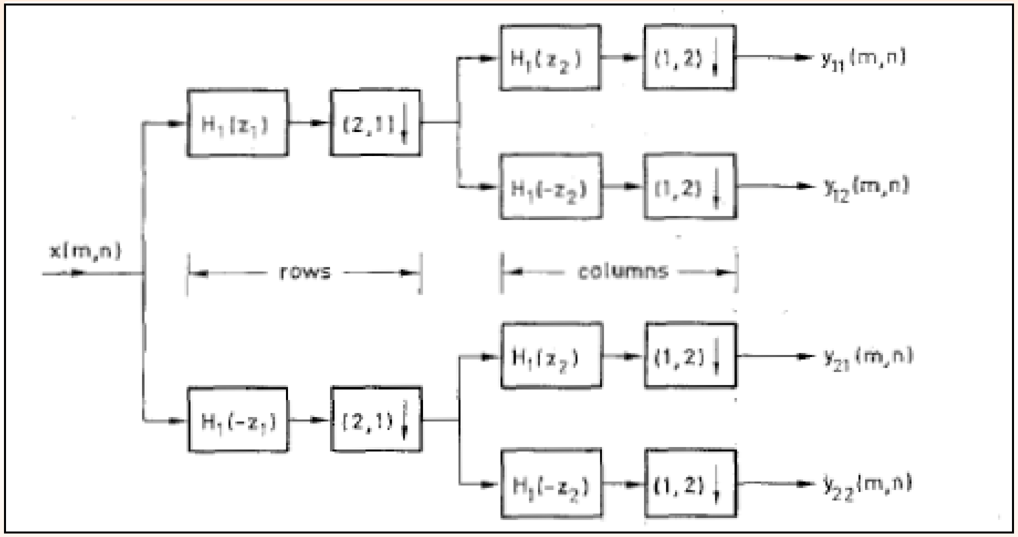
Subband Coding



Subband Coding Of Images

Subband Coding : Analysis





Subband Coding Of Images

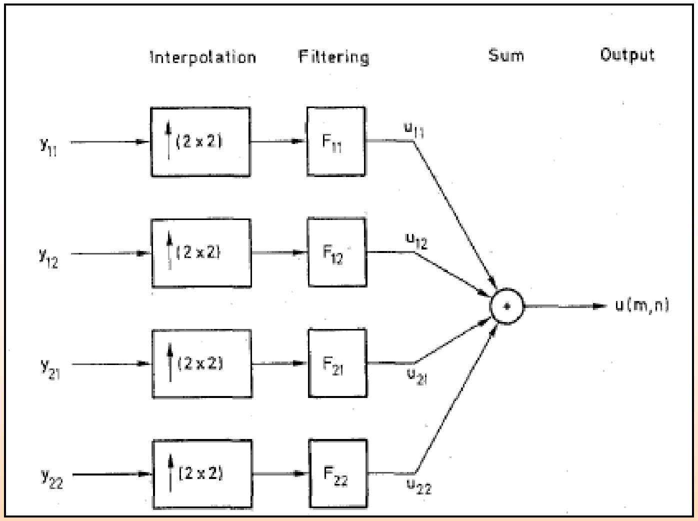
Subband Coding : Quantization and Coding

- Different subbands contain different amounts of information.
- Therefore the available bits are to be allocated among the subbands according to some measure of the information content.
- For example, suppose we are decomposing the image into 4 subbands and we want a coding rate of 1 bit per pixel, we can do this by using 1 bit per pixel for each subimage, or we could discard two subimages and use 2 bits per pixel for the remaining two subimages, or we could use all the 4 bits per pixel for the first subimage and discard the other three.

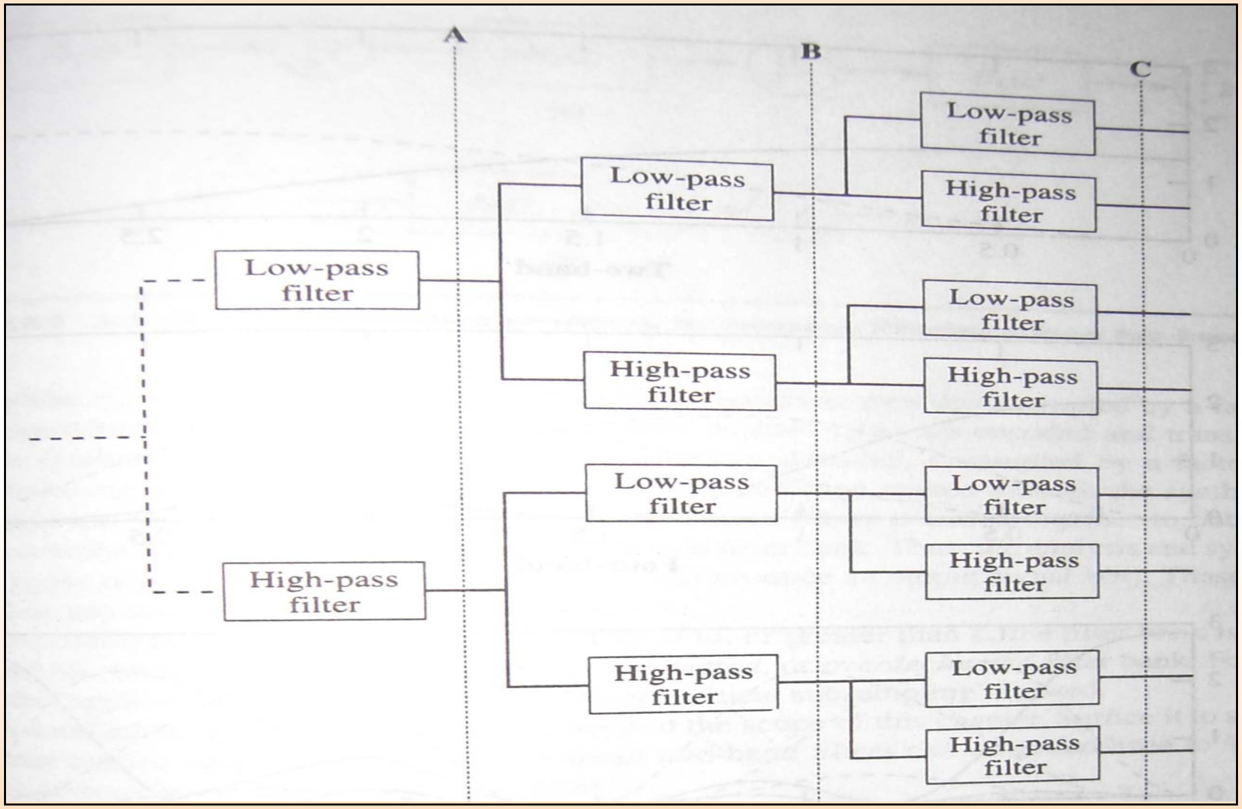
LL	LH
HL	HH

Subband Coding : Synthesis

- The encoded samples from each subband are decoded at first.
- The decoded values are then upsampled or expanded by introducing 0's between the samples.
- The upsampled signals are passed through a bank of reconstruction filters, the outputs of which can be added to give the final reconstructed outputs.



M-Band Subband Coding System



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- Image Compression Example
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Quantization and Coding : Recursive Bit Allocation

- The amount of information present in each sub-band is proportional to the variance of the coefficients of that subband.

- Algorithm :

  - ✓ Compute variances, var(k) for each subimage k = 1 to M
  - ✓ Set R(k) = 0 for all k and Rb = MR, where Rb is the total number of bits available for distribution and R is the required average bit rate.
  - ✓ Sort the variances { var(k) } . Suppose var(m) is the maximum.
  - ✓ R(m) = R(m) + 1 ; var(m) = var(m) / 2 ;
  - ✓ Rb = Rb – 1. If Rb = 0, then stop ; otherwise go to step 3.

- Following this procedure we can allocate more bits to subimage with higher variance and few or none to the ones with lower variances.

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Filters used in subband coding of Images

- Johnston Filter-bank and Smith-Barnwell filter-bank.
- Both the filter-banks use tree structure for decomposition of image.
- The high pass analysis filter and both synthesis filters are derived from low pass analysis filter by inspection.
- They come under the category of quadrature mirror filter banks.
- Number of taps in the filters can be varied.Trade-off involved between the efficiency of decomposition and the amount of computation.

Practical Filters : Johnston filter

Table 1 Coefficients for the 8-tap Johnston low-pass filter.

h0, h7	0.00938715
h1, h6	0.06942827
h2, h5	-0.07065183
h3, h4	0.48998080

Table 2 Coefficients for the 16-tap Johnston low-pass filter.

h0, h15	0.002898163
h1, h14	-0.009972252
h2, h13	-0.001920936
h3, h12	0.03596853
h4, h11	- 0.01611869
h5, h10	- 0.09530234
h6, h9	0.1067987
h7, h8	0.4773469

Practical Filters : Johnston filter

- Design of Johnston filter bank involves design of a two channel semi – PR QMF filters (semi – perfect reconstruction QMF).
- Such filters cannot satisfy all the three conditions for perfect reconstruction, namely alias cancellation, phase distortion and amplitude distortion elimination, together.
- Johnston filters satisfy alias cancellation and linear phase property. But they do not eliminate amplitude distortion completely.
- Alias cancellation is done by choosing $F_1(z) = H_2(-z)$ and $F_2(z) = -H_1(-z)$
- By using linear phase FIR filters, phase distortion is eliminated.
- Finally $H_1(z)$ is designed in such a way that Amplitude distortion is minimized and $H_2(z) = H_1(-z)$.

Practical Filters : Smith Barnwell Filters

Table 3 Coefficients of the 8-tap Smith-Barnwell low-pass filter.

h0	0.0348975582178515
h1	-0.01098301946252854
h2	-0.06286453934951963
h3	0.223907720892568
h4	0.556856993531445
h5	0.357976304997285
h6	-0.02390027056113145
h7	-0.07594096379188282

Practical Filters : Smith Barnwell Filters

- Unlike Johnston filter, Smith Barnwell filters form a perfect reconstruction system.
- Aliasing is avoided by choosing $F_1(z) = -H_2(-z)$ and $F_2(z) = H_1(-z)$.
- Analysis high pass filter is related to analysis low pass filter as :

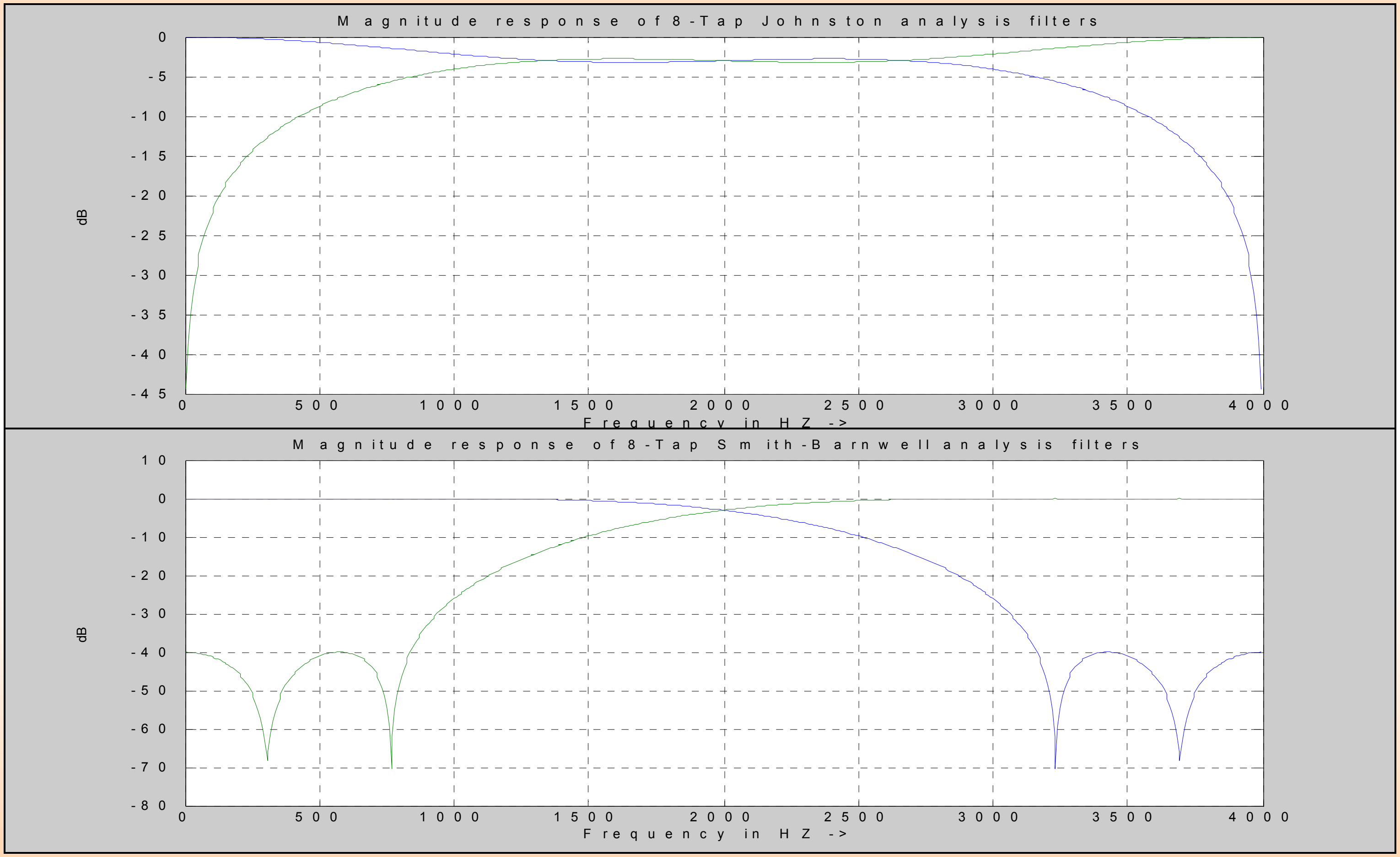
$$H_2(z) = z^{-N} H_1(-z^{-1}).$$

- It can be shown that perfect reconstruction requirement reduces to finding a prototype low-pass filter H(z) = H1(z) such that

$$H(z)H(z-1)+H(-z)H(-z-1) = \text{constant}.$$

Such a filter is called a power symmetric filter.

Johnston Vs Smith Barnwell Filters



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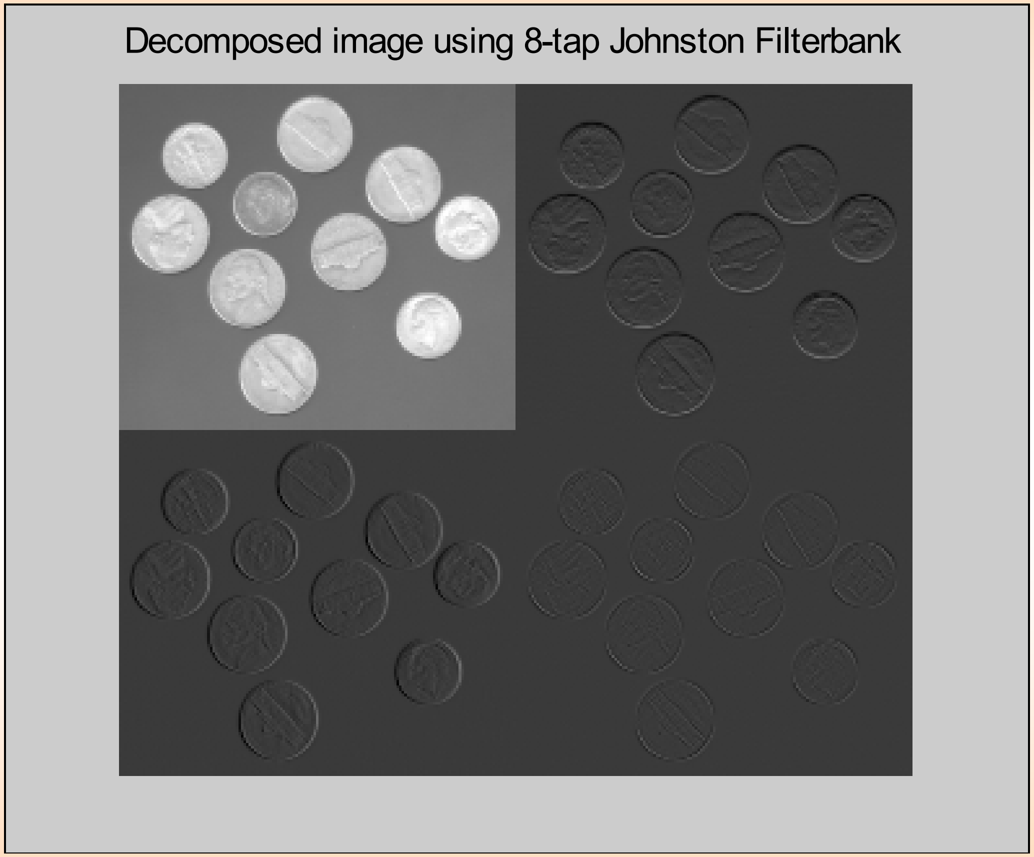
Subband Coding Of Images

Image Compression Example



Subband Coding Of Images

Image Compression Example

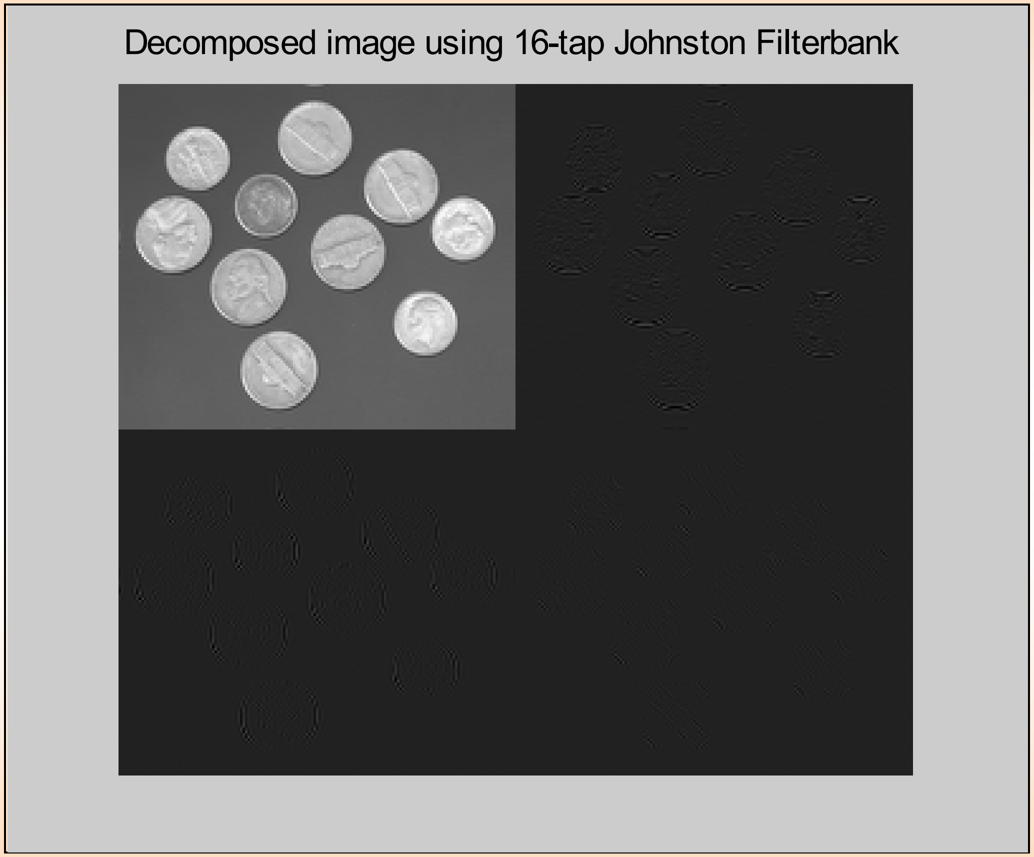


Image Compression Example

Subband Coding Of Images

Image Compression Example

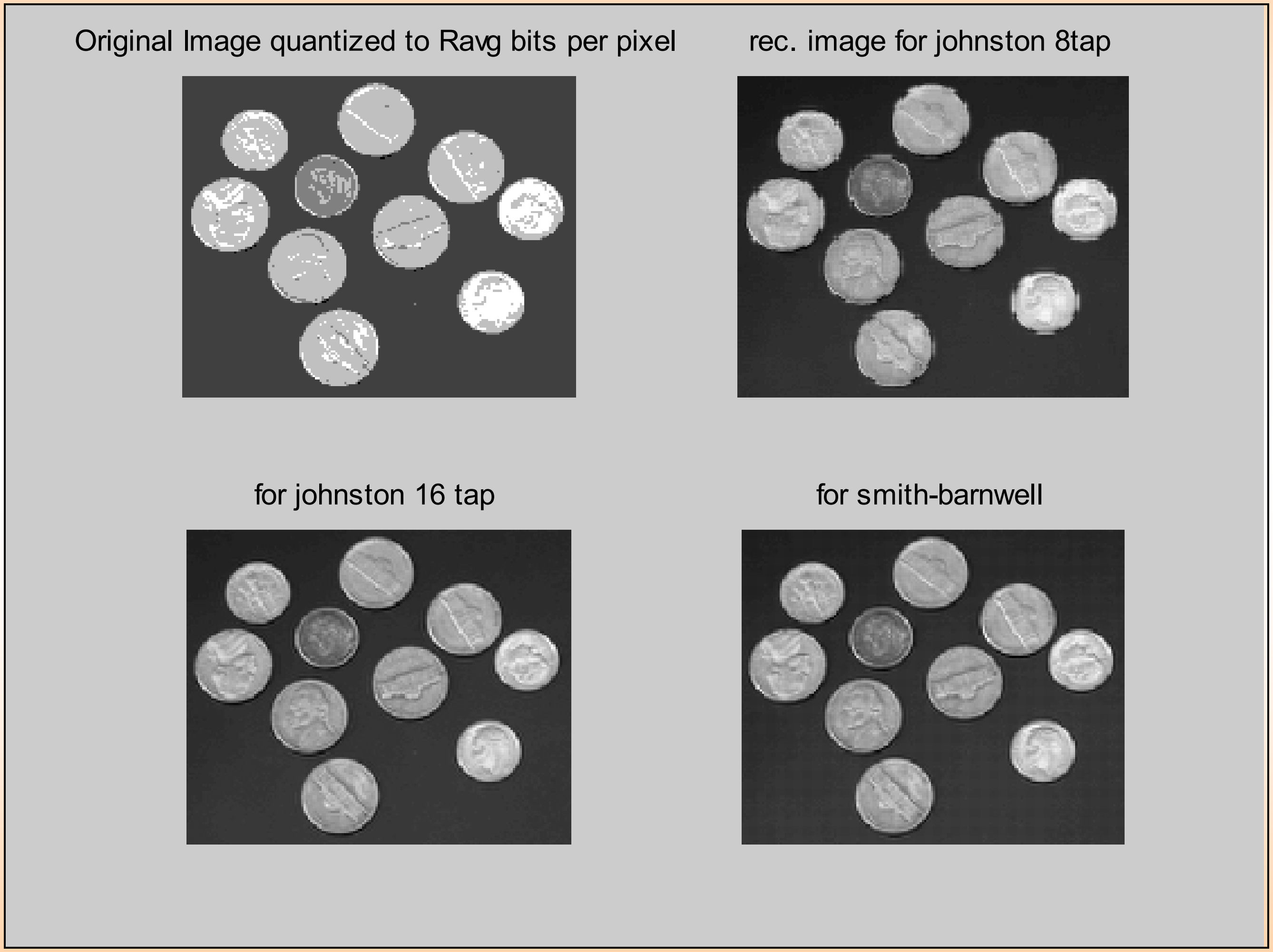


Image Compression Example

- In the image decomposed using 8-tap Johnston filter, there was significant energy in the LL, LH and HL bands. The algorithm allocated 6 bits to the LL band and 1 bit to the LH and HL bands. This resulted on poor encoding for both and subsequently poor reconstruction.

- In the image decomposed by 16-tap Johnston filter or the 8-tap Smith-Barnwell filter, most of the significant energy is concentrated in the LL band. Hence the algorithm allocated all the 8 bits to LL band, which provided a good reconstruction.

- The issue of energy compaction is also an important factor in reconstruction quality. Filters that allow more energy compaction permit allocation of available bits to a smaller number of subbands. This in turn results in a better reconstruction.

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Summary and Conclusion

- Subband coding is an important application of filter bank theory with large practical application.
- The advantage of subband coding lies in the decomposition of source image into different sub-images, each with a different frequency span and different characteristics and hence can be coded differently and more efficiently.
- The general subband encoding of image can be summarized as :

  - ✓ Select a set of filters (filter bank) for decomposing the image.
    The selection may involve a trade off between good reconstruction and number of computations.
  - ✓ Pass the image through the filter bank. Decimate the output of filter bank.
  - ✓ Quantize and encode the resulting sub-images.
  - ✓ Decoding and Synthesis can be done in exactly a reverse manner of encoding and analysis.

That was the last slide !

Thank you !!!

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