SIGNAL PROCESSING AND ITS APPLICATIONS

AVIDEH ZAKHOR

GENERAL OVERVIEW OF SIGNAL PROCESSING

- Digital vs analog vs discrete time.
- Theoretical vs applied.
- Algorithm development vs implementations.
- Applications:
  1. Telecommunications.
  2. Audio
  3. Speech
  4. Analog to digital conversion
  5. Video
  6. Images
  7. Radar
  8. Sonar
  9. Biomedical
  10. Geophysical

IMAGE PROCESSING

- Image enhancement → dynamic range/histogram modifications.
- Image restoration → debluring due to motion or being out of focus.
- Image reconstruction from partial information:
  1. Fourier transform phase.
  2. Fourier transform magnitude.
  3. Projection → projection slice theorem.
- Image compression for communications, storage, entertainment, etc. ..

VIDEO SIGNAL PROCESSING

- Implementation: VLSI architectures need to be resolved for real time operation.
- Algorithmic issues → Compression strategies:
  1. What to quantize:
     - Space domain information: pixels.
     - Frequency domain information: DCT or DFT.
     - Predictive coding: DPCM.
  2. How to quantize:
     - Uniform
     - Max - Loyd.
  3. How to allocate bits:
     - Entropy coding.
     - Arithmetic coding.
     - Hoffman coding.
- Motion Estimation:
  - Reduce redundancy → compression.
  - Frame interpolation → rate conversion.
  - Enhancement.

- Present research topics:
  - HDTV.
  - Video conferencing.
  - Compact disc $\rightarrow$ 1.5 Mb/sec.
  - Video communications over digital networks.

SPEECH

- Problems in speech:
  1. Analysis and Synthesis.
  2. Voiced/unvoiced discrimination, pitch detection.
  3. Coding $\rightarrow$ LPC coding, pole zero modeling.
  4. Speech recognition
     - Speaker dependent vs independent.
     - Connected words vs isolated words.
     - Vocabulary size.
     - Extensive training.
     - Error rate
     - Applications of AI for context dependent recognition.

AUDIO

- Problems in audio:
  1. Generation of signals $\rightarrow$ music synthesis.
  2. Storage and Transmission of signals $\rightarrow$ tapes, compact disc players.
  3. Restoration of old signals $\rightarrow$ Caruso's operas.
  4. Faithful reproduction of signals in the form of acoustic wave $\rightarrow$ Speaker design.
  5. Adding reverb.
  6. Echo removal.
  7. Adaptive cancellation for room/car acoustics.
  8. Precise analog to digital converter design $\rightarrow$ Sigma delta converters.

TELECOMMUNICATION

- Digital versus analog message source.
- Modulation techniques → AM vs FM vs PM.
- Error Correction Codes:
  - Block Codes.
  - Convolutional Codes.
- Compensation for channel nonidealities:
  - Atmospheric Fading.
  - Distortion → Adaptive equalization.
- Viterbi Decoding:
  - ISI.
  - CPM.
  - Convolutional decoding.

BIOMEDICAL APPLICATION

- Ultra sound.
- Magnetic Resonance Imaging.
- PET.
- X ray Tomography:
  - Projection slice theorem.
  - Application to other tomography problems such as NDE, radar, geophysics.
  - Limited angle tomography.

RADAR

- Principle of operation:
  - Estimate range by measuing time delay $\rightarrow$ short pulses.
  - Estimate doppler by measuring frequency of the received signal $\rightarrow$ Continuous wave such as sinuosid.
  - Tradeoff between range and doppler resolution.
  - Time compression waveforms. $\rightarrow$ matched filtering.
- High resolution Radar Imaging:
  - SAR $\rightarrow$ Optical Fourier Transform.
  - ISAR.

SONAR

- Similar to radar except for operating frequency and passive mode of operation.
- delay and direction of arrival estimation.
- Adaptive beamforming.
- Adaptive nulling to combat unwanted interference.

GEOPHYSICS

- Applications: Geology, Oil/mineral exploration.
- Signal processing techniques used: DECONVOLUTION: predictive, dynamic homomorphic.

IMPLEMENTATION ISSUES

- Fixed point versus floating point arithmetic.
- Accumulation of round off errors.
- Filter design and implementation: FIR versus IIR.
- Stability and robustness of algorithms.

ANALOG VERSUS DIGITAL

- Analog signal processing can handle up to 8 bits of accuracy.
- Advantages of digital:
  - Robustness with respect to aging and temperature.
  - Added flexibility.
- Which one is more appropriate for what?