Digital Signal Processing (Lecture Note 1)

Jin Ho Chang

Professor

Dept. of Electrical Engineering and Computer Science

DGIST 대구경북과학기술원 Daegu Gyeongbuk Institute of Science & Technology

Course Descriptions

- Techniques of modern digital signal processing
- Theory of Fourier series, Fourier transform, signal sampling, Z-transform
- Design and implementation of digital filters
- Application of digital signal processing techniques

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Tentative Syllabus

Week 1: Overview of typical measurement systems and their nature in aspects of signal processing

Week 2: Characteristics of linear time invariant systems

Week 3: Fourier series

Week 4: Fourier transform

Week 5: Sampling theory and Discrete time Fourier transform

Week 6: Discrete Fourier transform and data windowing

Week 7: Data windowing

Week 8: Midterm Exam

Tentative Syllabus

Week 9: Z transform

Week 10: Basic concepts of filtering

Week 11: Design of finite impulse response (FIR) filters

Week 12: Design of infinite impulse response (IIR) filters

Week 13: Structures for discrete-time systems

Week 14: Short-time Fourier transform

Week 15: Spectral analysis

Week 16: Final Exam

Grading Policy and Text Book

- Midterm Exam: 35%
- Final Exam: 35%
- Homework: 30%
- **Discrete-time Signal Processing**

(Third Edition, Alan V. Oppenheim & Ronald W. Schafer)

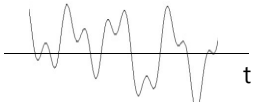
Typical Measurement Systems

What is a signal?

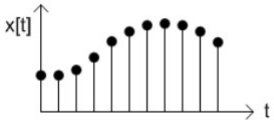
- Speech
- Biosignals
- A photographic image

→ Continuous, Discrete

1. Continuous-time signal



2. Discrete-time signals



Sequences of numbers

X={x[n]}, n is an integer

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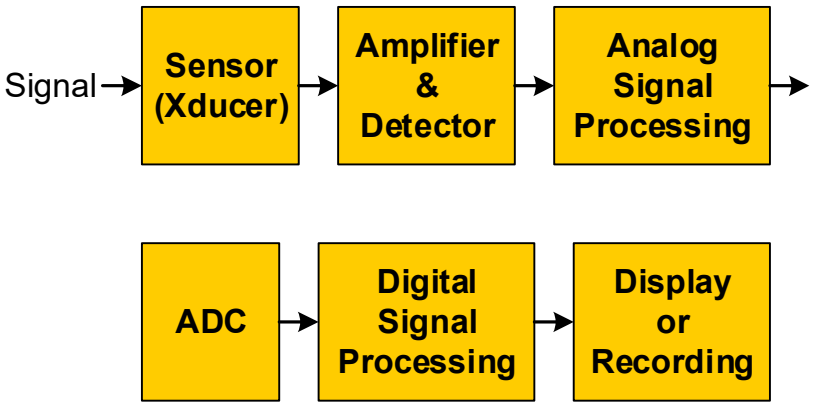
Typical Measurement Systems



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Sensor (Transducer)

- A transducer is a device that converts energy from one form to another.
  - Input: non-electrical energy
  - Output: voltage (or current) whose amplitude is proportional to the measured energy.
- A transducer frequently establishes the major performance criterion of a measurement system.
- A good system design usually calls for care in the choice or design of transducer elements.
  - An efficient, low-noise transducer design can often reduce the need for extensive subsequent signal processing and still produce a better measurement.

Analog Signal Processing

- Analog signal processing functions are usually placed in between a transducer and ADC (analog-to-digital converter).
- The first analog stage depends on the basic transducer operation.
  - If the transducer is based on a variation in electrical property, the first stage must convert that variation in electrical property into a variation in voltage.
  - If the transducer element is a voltage generator, the first stage is usually an amplifier.
  - If the transducer produces a current output, as is the case in many electromagnetic detectors, then a current-to-voltage amplifier (transconductance amplifier) is used to produce a voltage output.

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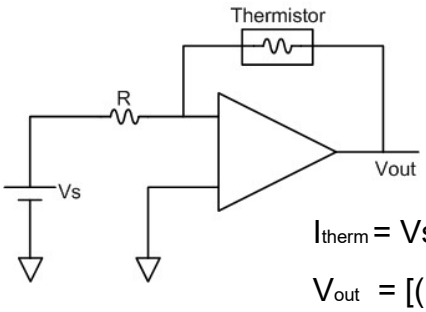
Example

- A device with an electrical resistance that decreases rapidly as its temperature rises, used in thermometers.

Vout = *I*(Z+ΔZ) where ΔZ = *f*(input energy)



$I_{therm} = Vs/R = constant$

$V_{out} = [(R_{therm}+\Delta R_{therm})/R]\cdot V_s$

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Analog Filters

- The analog signal processing circuitry will usually contain some filtering, both to remove noise and appropriately condition the signal for ADC.
  - All transducers and electronics produce some noise such as thermal noise from the transducer and other electronic components, flicker (or burst, or 1/f) noises from electronic components.
  - Thermal noise acting as a white noise usually contains a wide range of frequencies, and the burst noise has large spectral components in the dc and low frequency range.
  - Band-pass filtering removes those noise.
  - Low-pass or band-pass filtering makes the bandwidth of signals limited, thus making sampling error minimized in performing analog-to-digital conversion.

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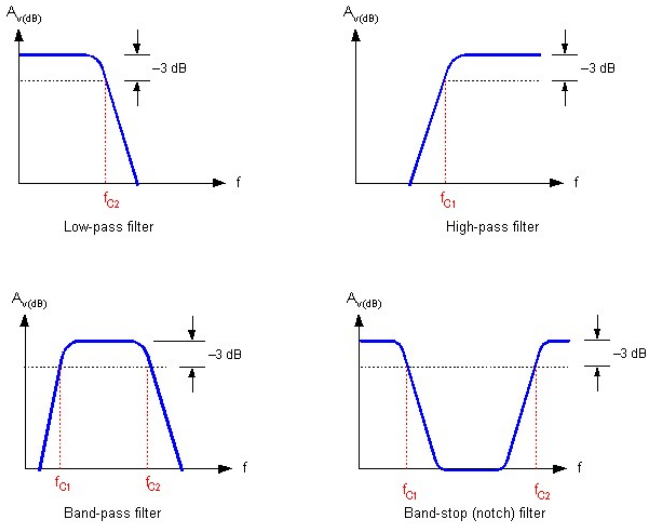
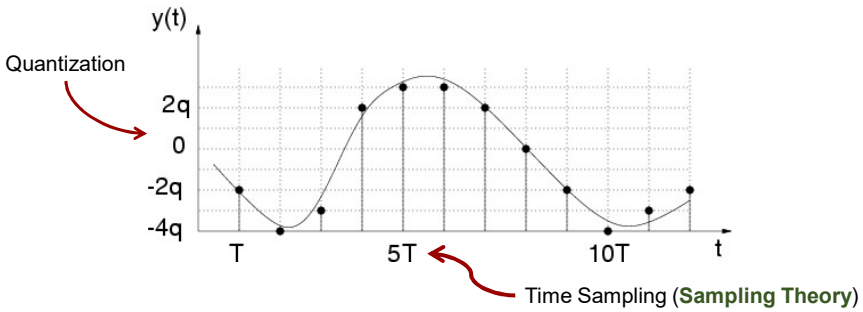
Filter Types



13

Analog-to-Digital Conversion

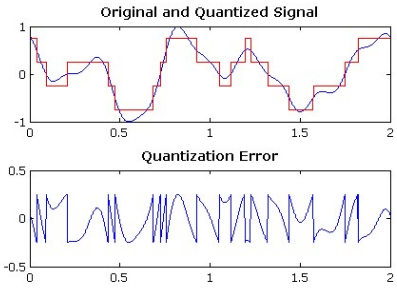
- ADC converts an analog voltage to an equivalent digital number.
  - To convert a continuous waveform to digital format requires slicing the signal in two ways: slicing in time and slicing in amplitude.

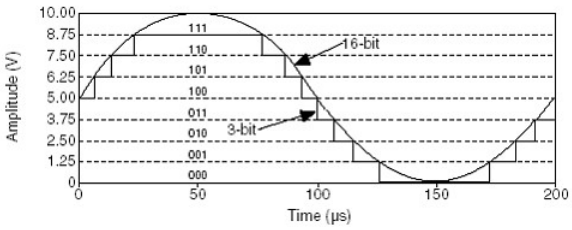


14

Quantization Error

- The number of bits used for conversion sets a lower limit on the resolution, and also determines the quantization error that can be thought of as a noise process added to the signal.
- 8-Bit vs. 12-Bit ADC
  - 12-Bit ADC has less quantization error than 8-Bit ADC



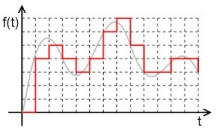


Digital Signal Processing

- Digital Filtering
  - Based on discrete Fourier transform (DFT), spectral analysis, z-transform, and Convolution
  - Signal separation and noise reduction
- Signal Enhancement
- Feature Extraction
- etc

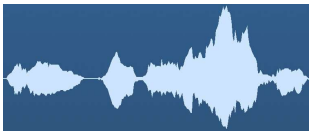
Example: Audio Signal Processing



Analog Signal Processing
ADC (Analog-to-Digital Converter)


Analog Signal

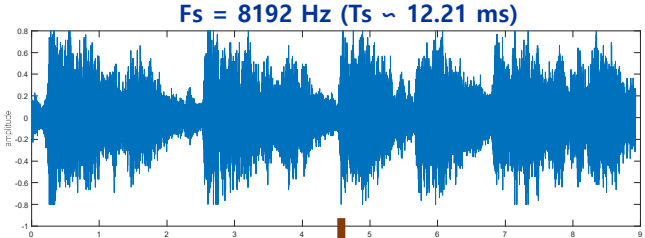
Digital Signal
Digital Signal Processing
Filtering
Audio Equalizer
etc

High Quality Audio Signal


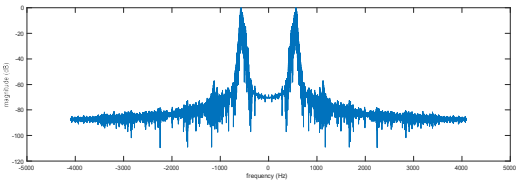
DAC (Digital-to-Analog Converter)

Digital Signal - Handel

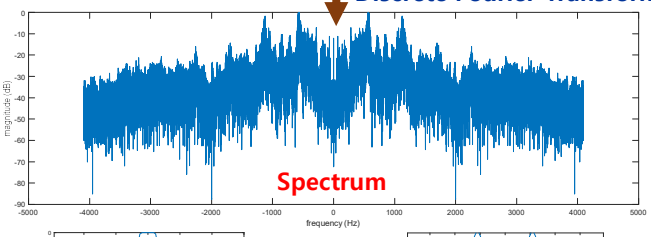
Fs = 8192 Hz (Ts ∽ 12.21 ms)



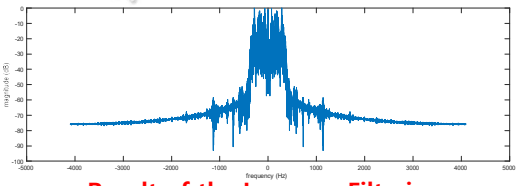
Discrete Fourier Transform



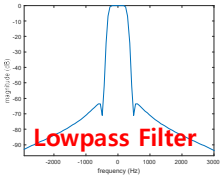
Result of the Bandpass Filtering



Spectrum

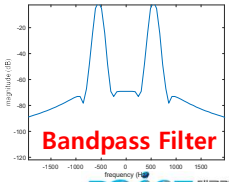


Result of the Lowpass Filtering



Lowpass Filter

Transfer Functions



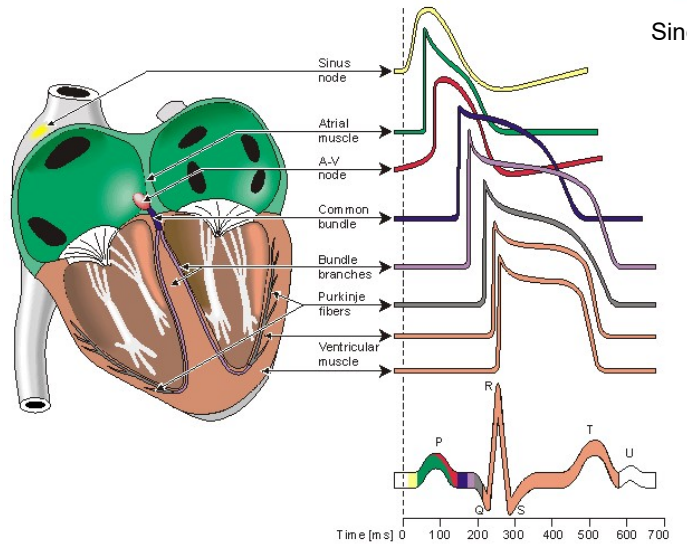
Bandpass Filter

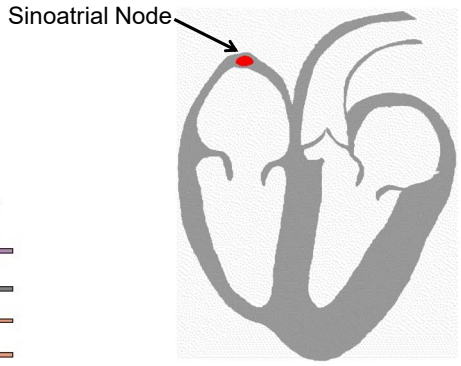
Example: ECG as a Biosignal

- A method to record bioelectric currents generated by the heart.
  - A routine investigation in patients who complain of symptoms such as chest pain and breathlessness.
  - Diagnosis of abnormal heart rhythms, i.e., heart disease: ischemic heart disease, hypertrophy patterns, atrioventricular (AV) block, etc.
- Electrical impulses in the heart begin from the sinoatrial node and travel through the intrinsic conducting system to the heart muscle.
  - The impulses stimulate the myocardial muscle fibers to contract, which is called "systole".

19

A Normal ECG Signal





20

Signal Processing for ECG

- Several electrodes (or leads) are used to acquire the bioelectric currents.
  - Generally noise and artifacts contaminate ECG signal because those unwanted signals are within the frequency band of interest.
- In order to extract useful information from the noisy ECG signals, signal processing should be conducted.
  - Preprocessing to remove or suppress noise from the raw ECG signals
    - ✓Baseline wandering removing and wideband noises suppression
  - Feature extraction processing to obtain diagnostic information from the preprocessed ECG signals
    - ✓QRS complexes detection, fetal heart rate extraction, and etc.

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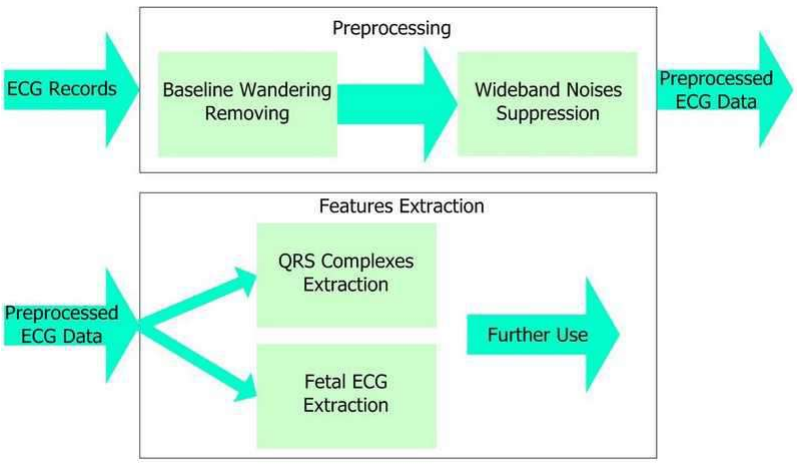
Typical ECG Signal Processing Flowchart



From http://zone.ni.com/devzone/cda/tut/p/id/6349

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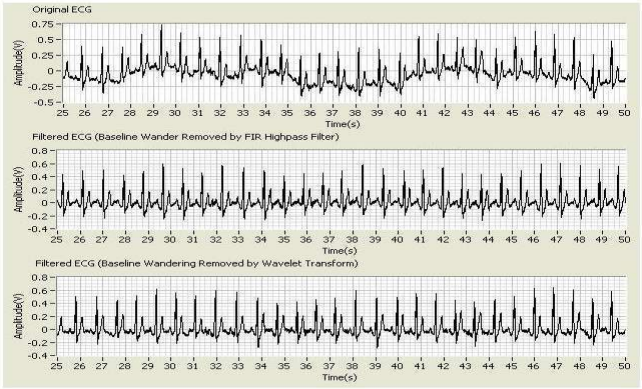
Preprocessing (1)

- Baseline wandering, a drift of a running average of the received signal power, can be suppressed by using
  - A high-pass digital filter because the signal consists of very low frequency components between 0.15 and 0.3 Hz.
  - The wavelet transform to eliminate the trend of the ECG signal



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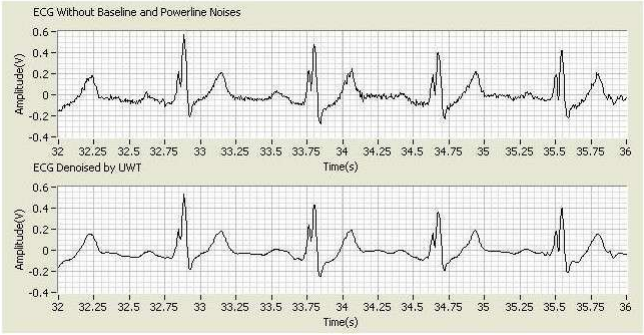
Preprocessing (2)

- Removing wideband noise can be done by using
  - Conventional digital filters
  - Wavelet transform method in which the ECG signal is first decomposed into several subbands, and then each wavelet coefficient is modified by applying a threshold or shrinkage function, and finally the denoised signal is reconstructed.



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Feature Extraction: QRS complex detection as an Example

- For the purpose of diagnosis, you frequently need to extract various features from the preprocessed ECG data including QRS intervals, QRS amplitudes, PR intervals, ST intervals, and etc.
- The detection of the QRS complexes in an ECG signal is carried out by the detection of the R-peaks.
  - This provides information about the heart rate, the conduction velocity, the condition of tissues within the heart as well as various abnormalities.
  - The presence of noise and time-varying morphology makes the detection difficult.
  - Wavelet-based detection methods can be used to extract the feature from noisy signals by multi-resolution analysis.

QRS Complex Detection

- This figure shows the ECG signals processed by wavelet multi-resolution analysis and peak/valley detection.
  - Wavelet multi-resolution analysis made the peaks and valleys more distinct.

Conclusions

ADC (Analog-to-Digital Converter)

- Sampling Theory
  - ✓ Selection of a sampling interval to avoid distortion

Basic Digital Signal Processing

- Filter Design
  - ✓ Based on Fourier transform
  - ✓ Based on spectrum analysis
- Filter Implementation
  - ✓ Based on z-transform

- Digital Image Processing
- Audio Signal Processing
- Biomedical Signal Processing
- Basic Knowledge for Deep Learning
- etc

Digital Signal Processing Depending on Applications