PAM3012
Digital Image Processing for Radiographers

Analog to Digital Conversion

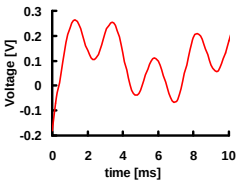
In this lecture

★Analog & Digital Signals
★Analog to Digital Conversion (ADC)
★Sampling
★Limitations

Analog & Digital Signals

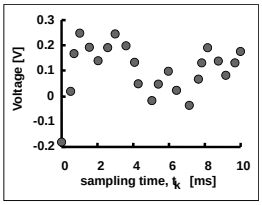
Analog

Continuous function V of *continuous* variable t (time, space etc) : V(t).



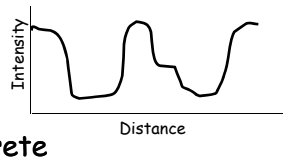
Digital

Discrete function V_k of *discrete* sampling variable t_k, with k = integer: $V_k = V(t_k)$.

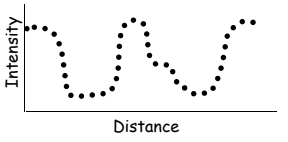


Analog and Digital Signals

- Continuous



- Discrete



Digital Signals

- Binary
  - Base two number system
- Binary Integer
  - BITS
  - ON or OFF
- 8 bit bytes

Signals in Medical Imaging

- Computer Radiography:
  - Voltage proportional to light intensity
- Direct Digital Radiography:
  - Voltage proportional to X-ray intensity
- Computed Tomography:
  - Voltage proportional to X-ray intensity
- Ultrasound:
  - Voltage proportional to US intensity

Analog or Digital?

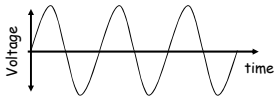
Advantages of Digital Signal

- High noise immunity
- Adjustable precision
- Ease of design (automation) and
- Fabrication, therefore, low cost
- Better Reliability
- Less need for calibration and maintenance
- Ease of diagnosis and repair
- Easy to duplicate similar circuits
- Easily controllable by computer

Disadvantages of Digital Signals

- Lower speed
- Needs converters to communicate with real world, therefore more expensive and less precision
  - Digital to Analog (D/A)
  - Analog to Digital (A/D)

Analog to Digital Converter



Sampling

- Sample signal intensity at discrete intervals
- Signal intensity binned into discrete levels
- Number of levels governed by number of bits

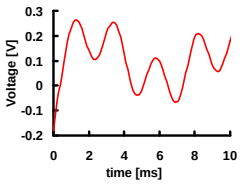
Analog to Digital Conversion

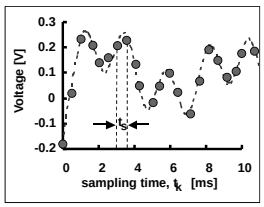
Analog

Continuous function V of *continuous* variable t (time, space etc) : V(t).

Digital

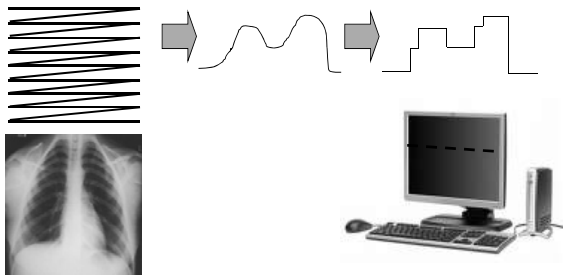
Discrete function V_k of *discrete* sampling variable t_k, with k = integer: $V_k = V(t_k)$.





Uniform (periodic) sampling.
Sampling frequency $f_S = 1/t_S$

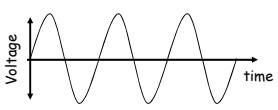
Example: Computed Radiography

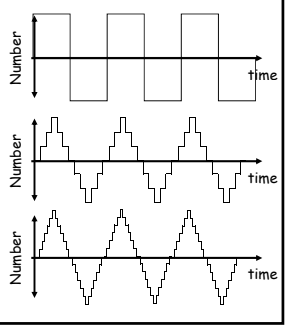


Analog to Digital Converter

Analog Signal:
Voltage varying continuously
e.g. -5 to 5 volts

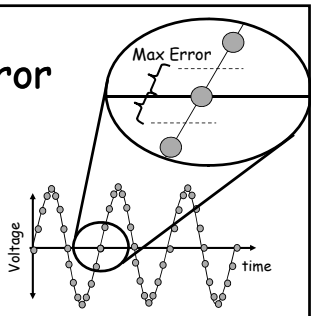
Digital Signal:
2^N discrete levels
(where N = number of Bits)





Quantisation Error

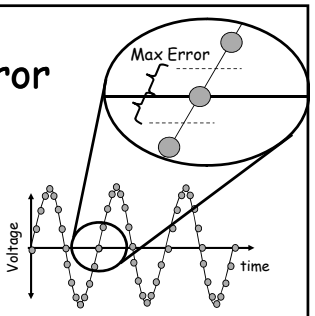
- Digital Accuracy depends upon number of bits of ADC.
- Maximum Error
  - Analog signal amplitude range, A
  - Digital increment size, N
  - Number of bits, n
  - Maximum quantisation error is equal to half the voltage of the least significant bit



$$q_{\max} = \frac{A}{2N} = \frac{A}{2^{n+1}}$$

Quantisation Error

- Digital Accuracy depends upon number of bits of ADC.
- Average Error
  - Average error is equal to half the maximum error



$$q_{av} = \frac{1}{2} q_{\max} = \frac{A}{4N} = \frac{A}{2^{n+2}}$$

Dynamic Range

- Range of values in each pixel *gray-scale range , dynamic range or Bit-depth*
- Numerical range in each pixel
- Visually: number of shades of gray that can be represented
- Number of levels = 2^n
  - Where n = number of bits

Dynamic Range

- 8-Bits

2^8 -> 256 shades

- 3-Bits

2^3 -> 8 shades

- 1-Bits

2^1 -> 2 shades

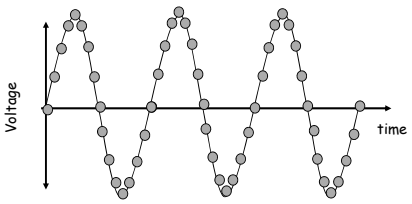
Example

An analog signal of amplitude 12v is sampled with a 8-bit ADC.

Calculate the maximum & average quantisation noise

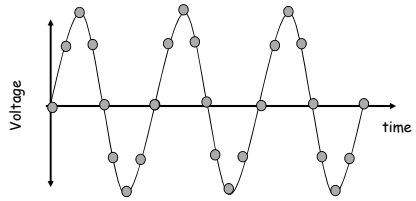
Analog to Digital Converter

- Sample rate (spatial & temporal)



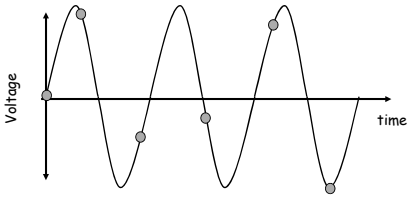
Analog to Digital Converter

- Sample rate (spatial & temporal)
- Reduce sample rate:



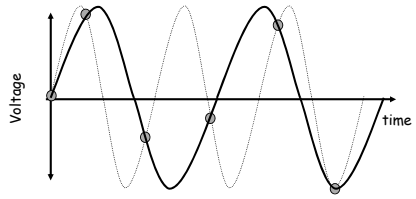
Analog to Digital Converter

- Sample rate (spatial & temporal)
- Reduce sample rate:



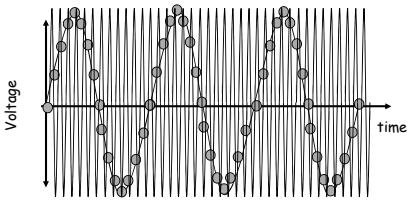
Analog to Digital Converter

- Sample rate (spatial & temporal)
- Reduce sample rate: Aliasing



Analog to Digital Converter

- Sample rate (spatial & temporal)



Nyquist Sampling Theorem

An analog signal containing components up to a maximum frequency of f may be completely represented by regularly spaced samples of $2f$

Sampling rate, T

$$T = 1/2\ f$$

Summary

★Analog & Digital Signals

★ADC

★Sampling

★Limitations