







Sampling - Reconstruction

- A/D: Analog to Digital converter *to read the analog signals into the micro-controller*

The process is called **SAMPLING**

- D/A: Digital to Analog converter to take the desired control signals out of the micro-controlled and present them in a form whereby they can be applied to the physical process

The process of signal **RECONSTRUCTION**







Converting an analog signal into a digital signal: A/D

- A/D conversion is characterized by two **discretizations**
 - The first concerns **TIME**, and is known as *sampling*: this involves taking samples of the analog signal at regularly spaced instants
 - The second concerns **AMPLITUDE** and is called *quantization*: it consists in coding the signal amplitude on a finite number of binary elements



Choices to be made when digitizing an analog signal

OLYTECH

Discretization accuracy via the choice of the sampling frequency (*f_s*)
- f_s must be sufficiently high so as not to loose information about the signal

– However, the higher f_s , the shorter the time available for numerical calculations and the greater the number of samples to be processed

How can we choose the sampling frequency f_s ?

$$f_{\rm s} = \frac{1}{T_s}$$
 where T_s is the sampling period

UNIVERSITÉ DE LORRAINE



Sampling theorem (Shannon 1949)



Harry Nyquist 1889-1976



UNIVERSITÉ DE LORRAINE

A band-limited signal x(t) in the frequency range $[-f_{max}; +f_{max}]$ can be

reconstructed exactly from its samples

if $f_s > 2 f_{max}$

The limiting frequency $\frac{f_s}{2}$ is called the *Nyquist frequency*





- Shannon's theorem only gives a **lower bound** on the sampling frequency that must not be exceeded
 - In practice, we need to choose a **much higher** sampling frequency
- The frequency f_{max} is rarely known precisely
 - It is necessary to filter the analog signal with a low-pass analog filter. Such a filter is called an *anti-aliasing filter*
- <u>For digital control</u>, the choice of the sampling period is more complex
 - It depends on the characteristics of the desired closed-loop response and therefore it depends on the desired performance



Practical chain for analog-to-digital conversion (A/D)

• In practice:

POLYTECH

- It is essential to precede the sampling operation with a **low-pass filter** called an *anti-aliasing filter*, with a cut-off frequency f_c slightly lower than the Nyquist frequency $f_c \approx f_s / 2$
- The practical chain for converting an analog signal into a digital signal therefore consists of the following elements



Analog-to-digital operation (A/D) Simplified representation

UNIVERSITÉ DE LORRAINE

POLYTECH

• The usual representation of the A/D operation consists in representing only the sampler block (the anti-aliasing filter and quantization blocks are not represented)









Digital-to-analog conversion (D/A) Practical reconstruction UNIVERSITÉ DE LORRAINE

POLYTECH

• The most common D/A operation consists in producing a continuous-time control signal *u*(*t*) from the sampled values *u*(*k*) by keeping *u*(*k*) constant throughout the sampling period via a **zero-order hold** (*ZOH*)







