TI-RSLK

Texas Instruments Robotics System Learning Kit

Texas Instruments

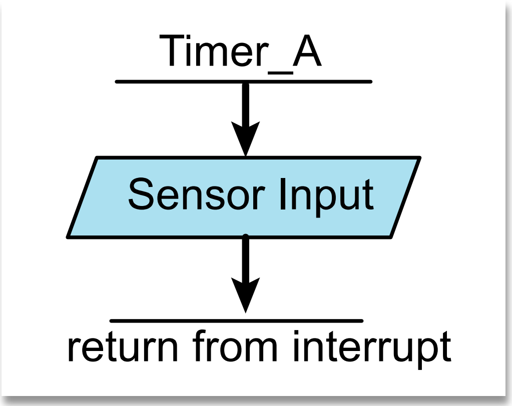
Module 15

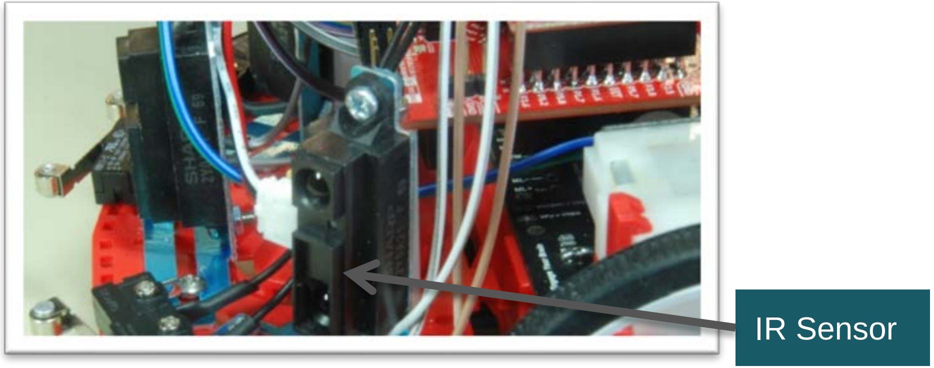
Lecture: Data Acquisition Systems - Theory

Data Acquisition Systems

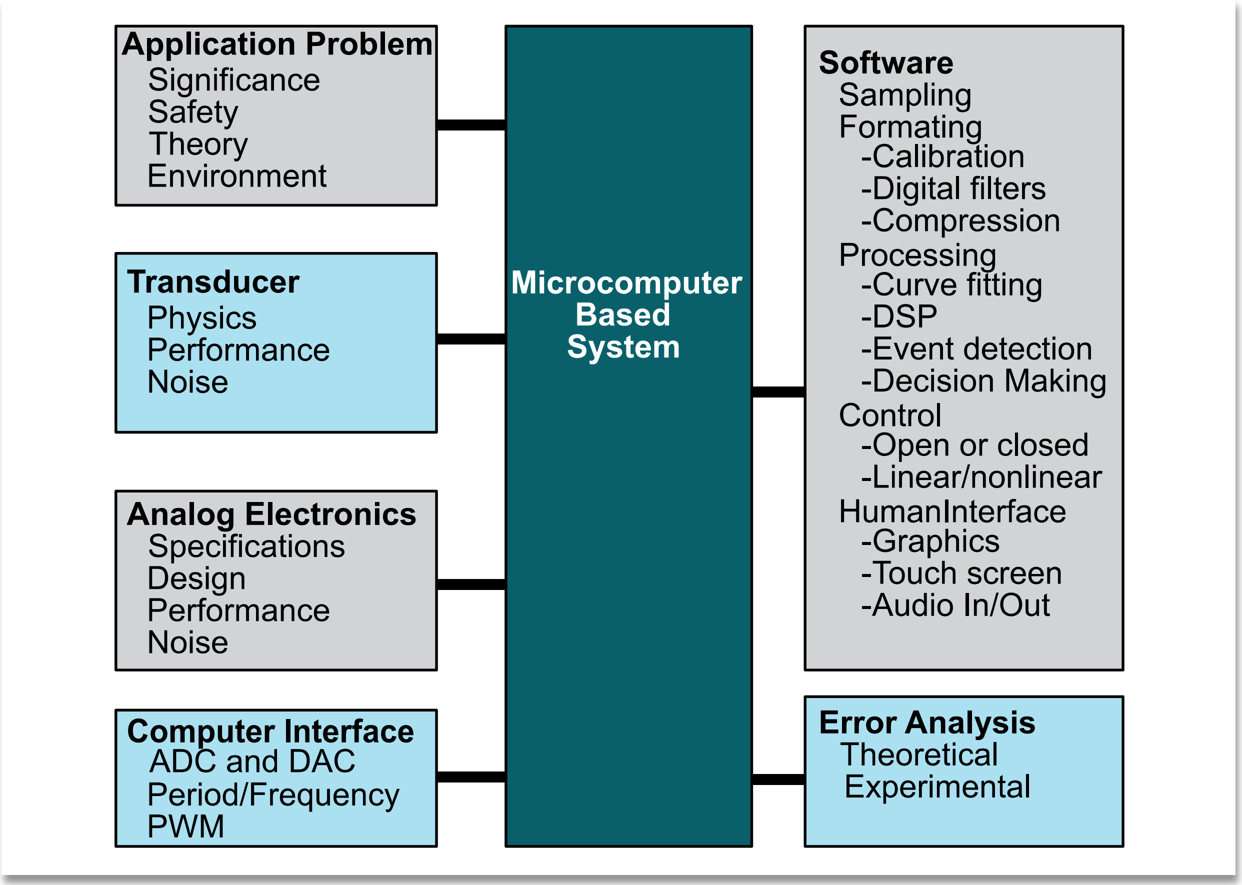
You will learn in this module

- Signals & Sampling
  - ADC, DAC
  - Range, resolution, precision
  - Successive approximation
- MSP432
  - Software driver
  - Spectrum Analyzer
  - Central Limit Theorem

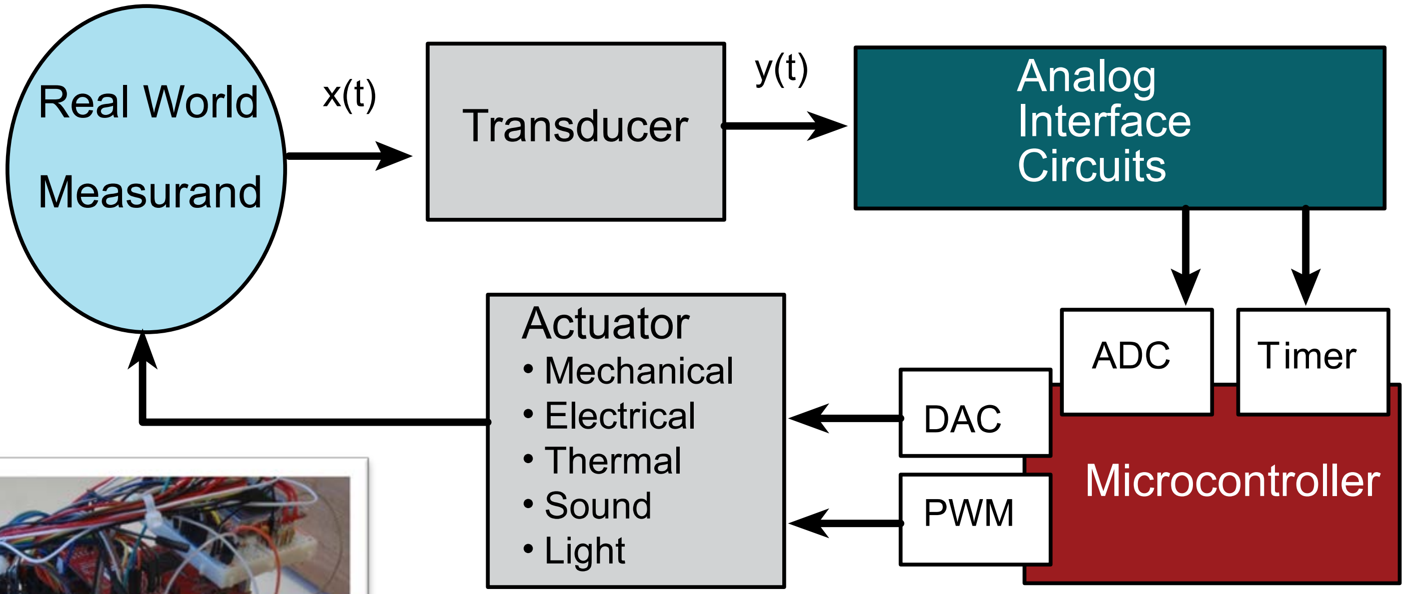


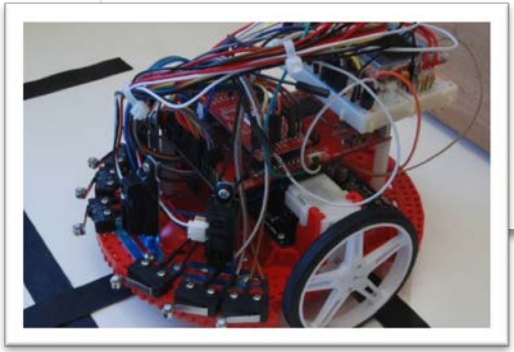


Data Acquisition Systems



A Control System includes a Data Acquisition System





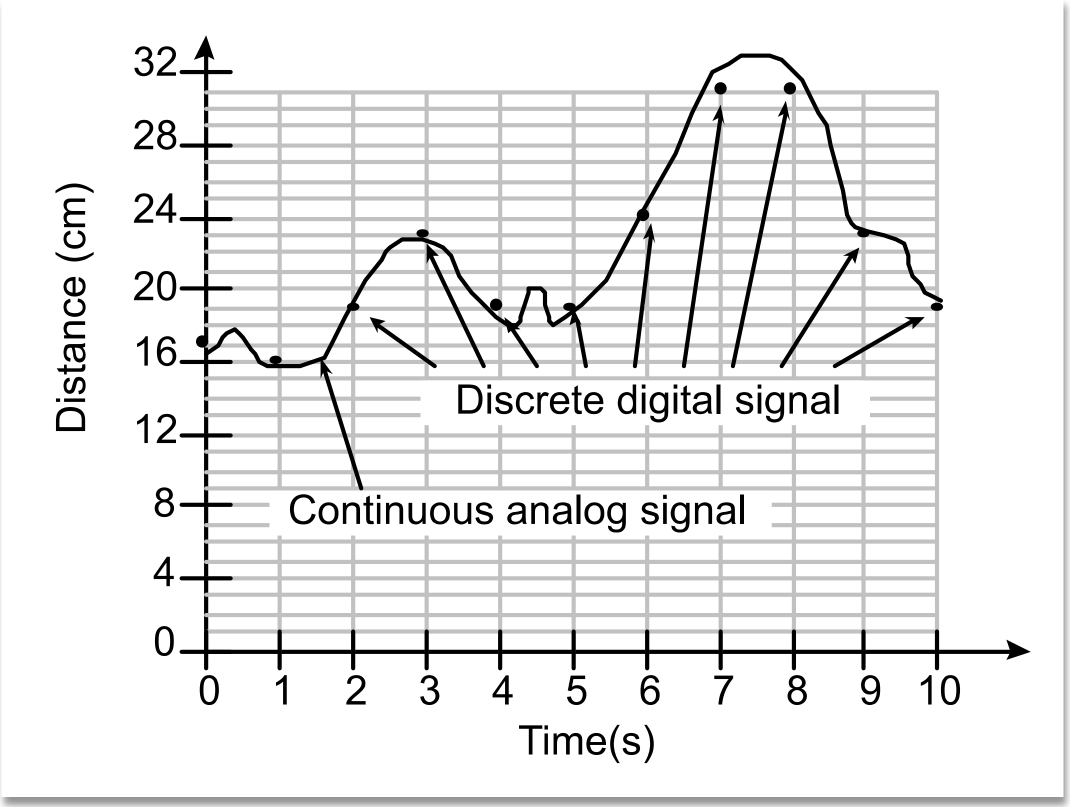
Sampling: conversion from analog to digital

Amplitude

- Range
- Resolution
- Precision

Time domain

- Sampling rate, f_s
  - 0 to ½ f_s
- Number of samples
  - Buffer size N
- Frequency resolution
  - f_s/N



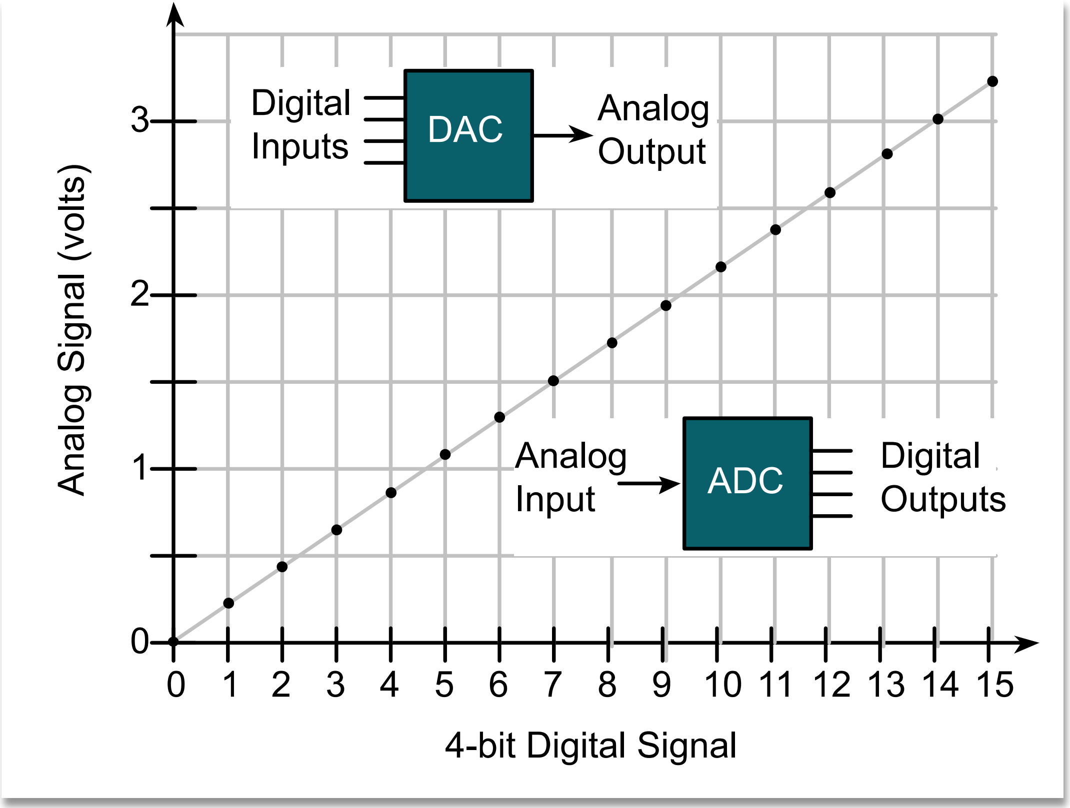
DAC versus ADC

DAC

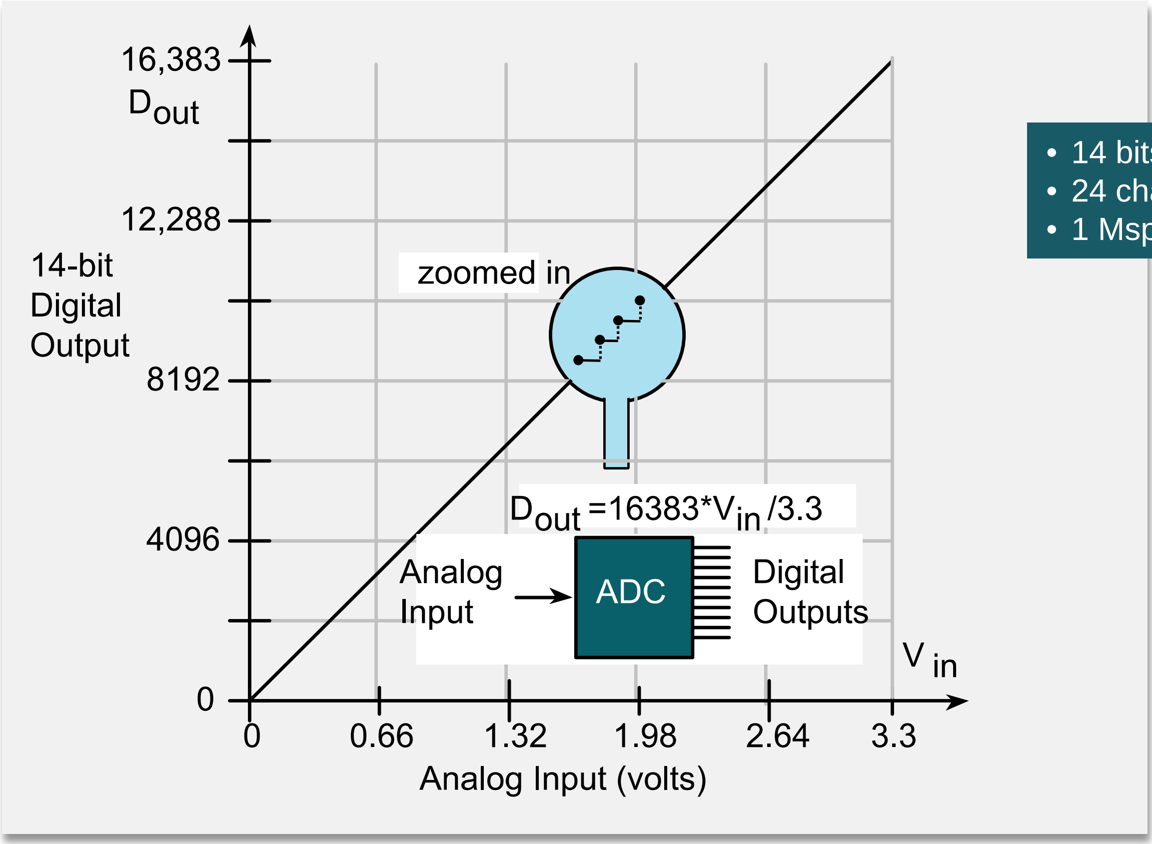
- Digital to Analog
- uC output
- Signal generation

ADC

- Analog to Digital
- uC input
- Measurements



MSP432 ADC14



- 14 bits
- 24 channels
- 1 Msps

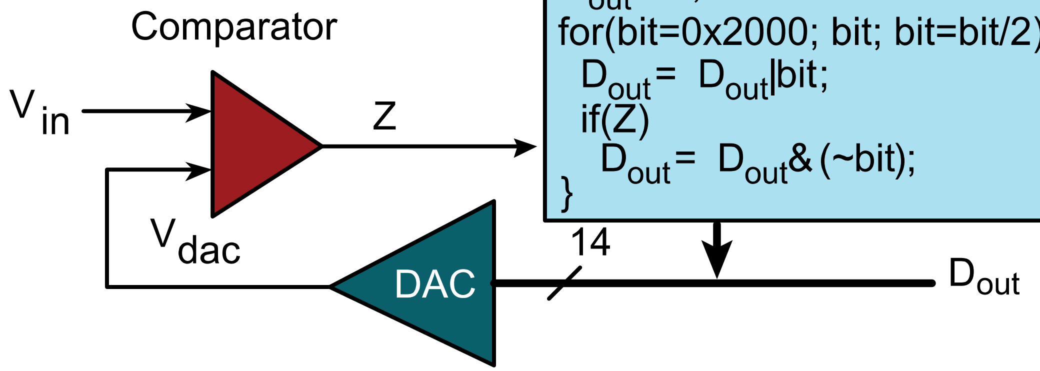
Successive Approximation

8-bit Successive Approximation Game

- I pick a number from 0 to 255
- You can guess
- I will respond high or low (same)
- How many guesses will it take you?

What is your first guess?

Successive Approximation – How it works




```
Dout =0;
for(bit=0x2000; bit; bit=bit/2){
  Dout= Dout|bit;
  if(Z)
    Dout= Dout&(~bit);
}
```

8-bit Successive Approximation Game

- You asked, “what is bit 7?”
- You asked, “what is bit 6?”

…

- You asked, “what is bit 0?”

- Uses a DAC
- Uses a comparator
- 1 bit/clock

Good information https://e2e.ti.com/blogs_/b/msp430blog/archive/2016/05/10/how-to-leverage-the-flexibility-of-an-integrated-adc-in-an-mcu-for-your-design-to-outshine-your-competitor-part-1

ADC14 Software Initialization

ADC14->CTL0

31-30	29-27	26	25	24-22	21-19	18-17	16
PDIV	SHSx	SHP	ISSH	DIVx	SSELx	CONSx	BUSY
15-12	11-8	7	6-5	4	3-2	1	0
SHT1x	SHT0x	MSC		ON		ENC	SC

- Clock (speed/power)
- Sample and hold (noise)
- Sequence or single channel
- Reference (range)
- Enable
- Start sample

ADC14 Software Initialization

ADC14->CTL1

31-28	27 – 24	22	21	20-16
	CH3MAP – CH0MAP	BATmap		CStartAdr

15-6	5 – 4	3	2	1-0
	RES	DF	REFBURST	PWRMD

- Address
- Resolution
- Format
- Power

ADC14->IFGR0

31		5	4	3	2	1	0
IFG31	…	IFG5	IFG4	IFG3	IFG2	IFG1	IFG0

- Conversion complete

ADC14 Software Initialization

ADC->MCTL[n]

31-16	15	14	13	12	11-8
	WINCTH	WINC	DIF		VRSEL

7	6	5	4 – 0
EOS			ADC14INCHx

- Comparator
- Differential/single
- Reference
- Channel

ADC14 Software Conversion

1. Wait for BUSY to be zero
2. Start conversion
3. Wait for completion
4. Read result

```
uint32_t ADC_In6(void){
  while(ADC14->CTL0&0x00010000){};
  ADC14->CTL0 |= 0x00000001;
  while((ADC14->IFGR0&0x01) == 0){};
  return ADC14->MEM[0];
}
```

Periodic Interrupt and Mailbox

1. Sample ADC
2. Run digital filter
3. Save in global
4. Set semaphore

```
void SysTick_Handler(void){
  uint32_t RawADC;
  P1OUT ^= 0x01;
  P1OUT ^= 0x01;
  RawADC = ADC_In6();
  ADCvalue = LPF_Calc(RawADC);
  ADCflag = 1;   // semaphore
  P1OUT ^= 0x01;
}
```

9us

Summary

Analog to Digital Converter

- Successive Approximation
- Range
- Resolution
- Precision

Software

- Initialization
- Mailbox

$$\frac{100}{n}\sum_{i=0}^{n}\frac{\left|x_{ti}-x_{mi}\right|}{x_{t\max}}$$

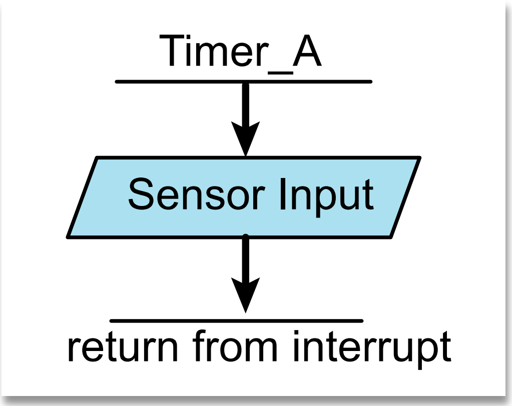
Module 15

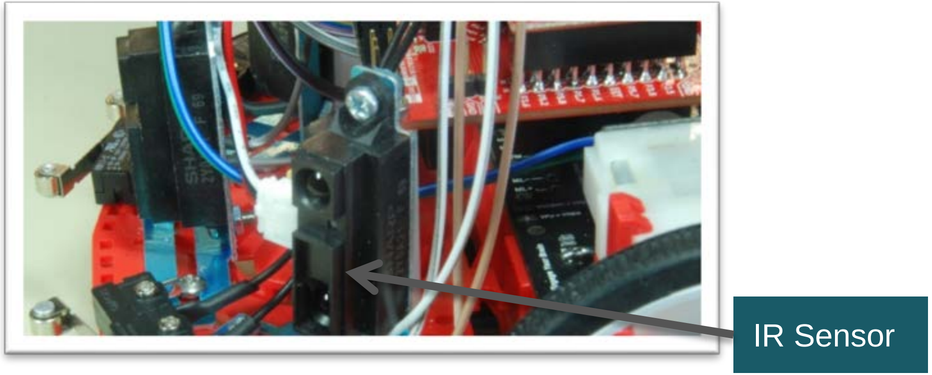
Lecture: Data Acquisition Systems – Performance Measurements

Data Acquisition Systems

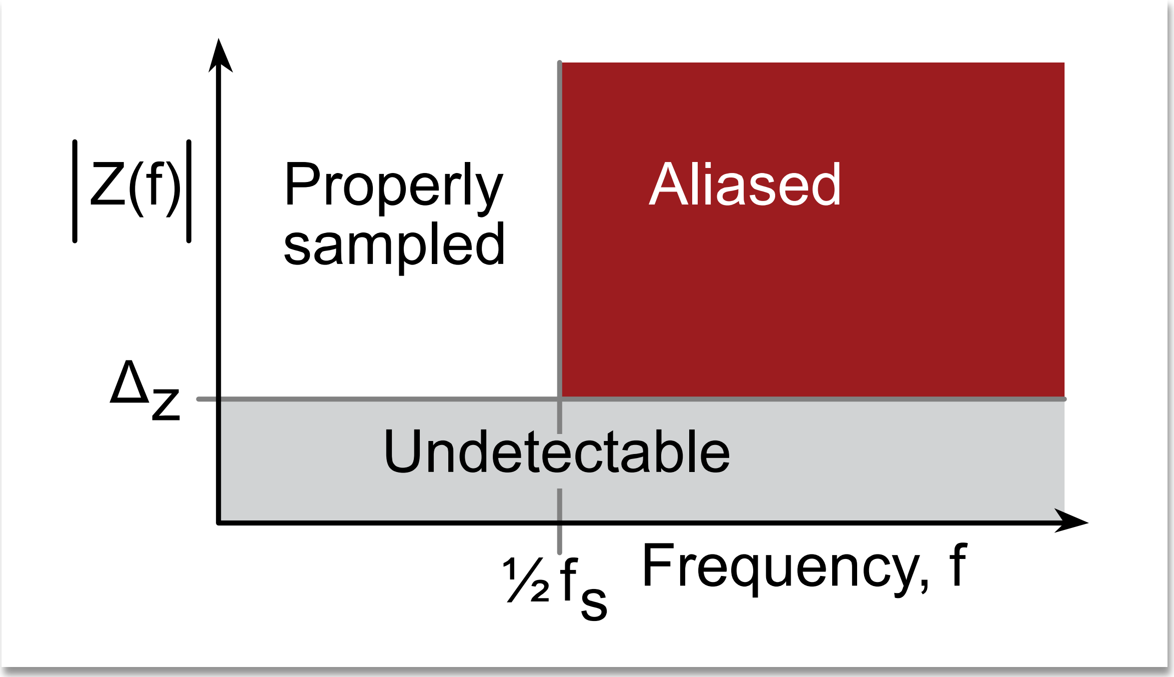
You will learn in this module

- Analog to Digital Converter
  - Sampling, Nyquist Theorem
  - Digital filtering
- Noise and statistics
  - Probability Mass Function
  - Spectrum Analyzer
  - Central Limit Theorem
- Data Acquisition Systems
  - Range, resolution, precision
  - Calibration
  - Accuracy





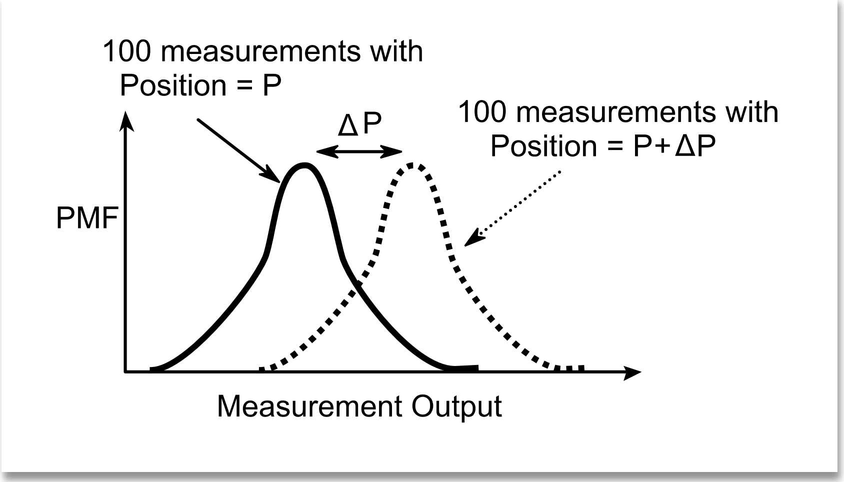
Nyquist Theorem



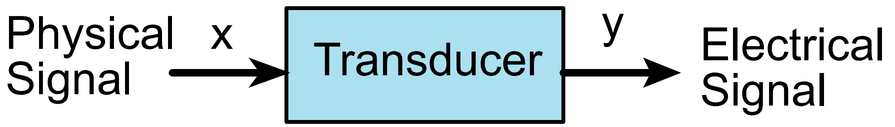
The **Nyquist Theorem** states that if the signal is sampled with a frequency of f_s, then the digital samples only contain frequency components from 0 to ½ f_s.

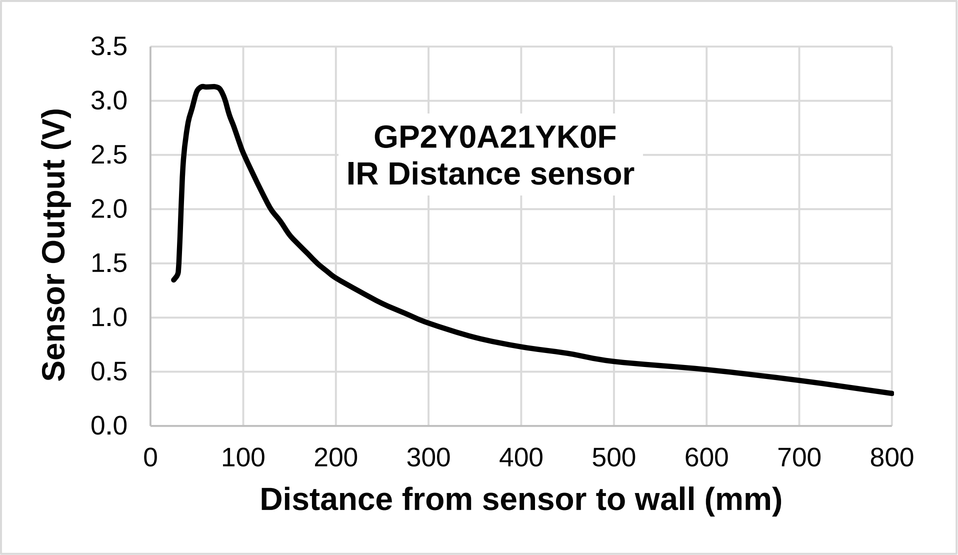
Statistics

- Probability Mass Function (PMF)
- Average (μ = mean)
- Standard deviation (σ = sigma)
- Range (max-min)
- Coefficient of variation, CV = σ/μ
- Precision $\log_2(\mu/\sigma)$
- Resolution, Δ



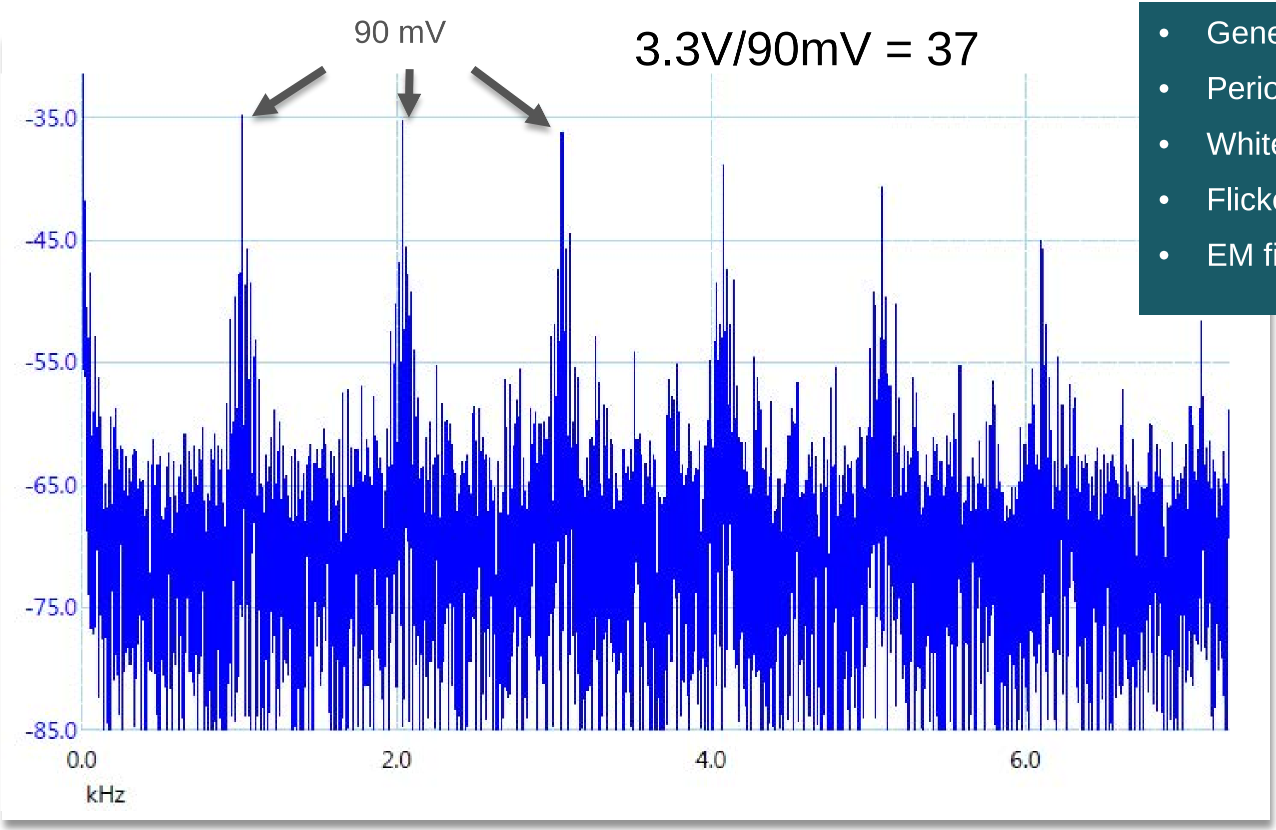
Transducer





- Nonmontonic
- Hyperbolic
- Noisy

GP2Y0A21YK0F IR distance sensors are noisy



3.3V/90mV = 37

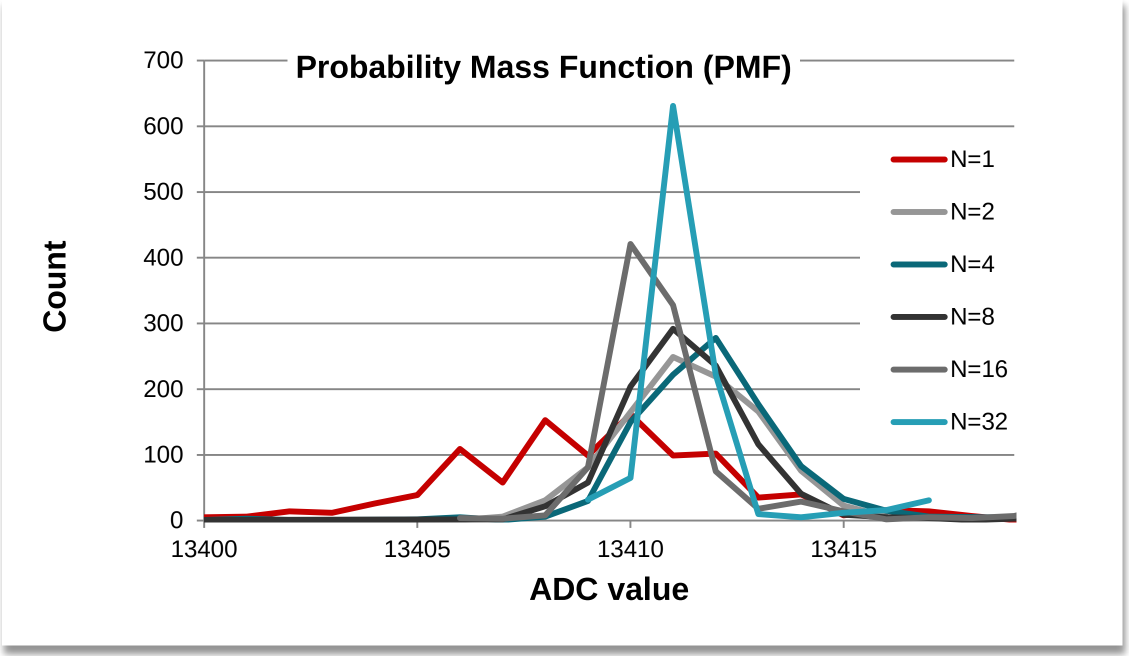
- Generation/recombination
- Periodic
- White
- Flicker, 1/f
- EM field pickup

50 Hz analog LPF

16 Hz digital LPF

$dB_{FS} = 20 \log_{10}(V/3.3)$

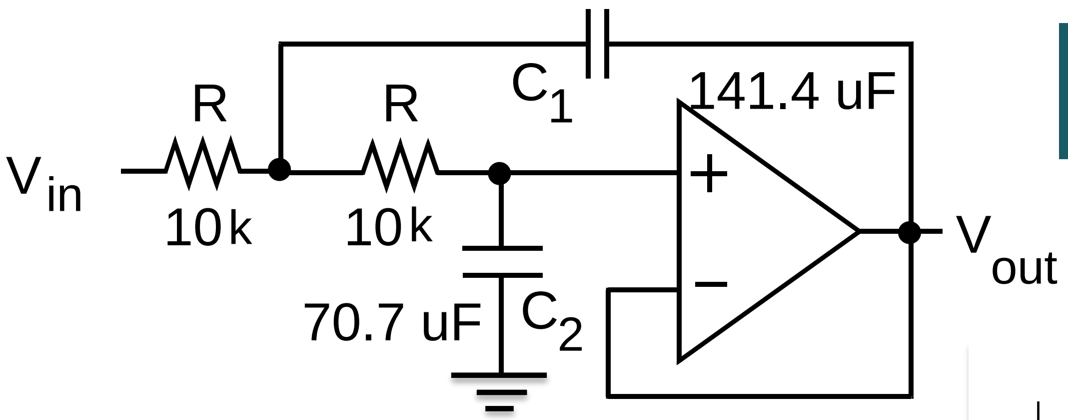
Probability Mass Function (PMF)



CLT states that as independent random variables are added, their sum tends toward a Normal distribution.

- Constant input
- Average of last N samples
- f_s = 1000 Hz

Analog Low Pass Filter to remove Aliasing



Two-pole Butterworth LPF

$$\left|\frac{V_{out}}{V_{in}}\right| = \sqrt{\frac{1}{1+\left(f / f_c\right)^4}}$$

1) Select the cutoff frequency, f_c (50 Hz)

2) Divide the two capacitors by $2\pi f_c$ (let C_{1A}, C_{2A} be the new values)

$C_{1A} = 141.4\mu F/2\pi f_c$ (0.45µF)

$C_{2A} = 70.7\mu F/2\pi f_c$ (0.225µF)

3) Locate two standard value capacitors (with the 2/1 ratio)

$C_{1B} = C_{1A}/x$ (0.44µF, two 0.22 µF in parallel)

$C_{2B} = C_{2A}/x$ (0.22µF)

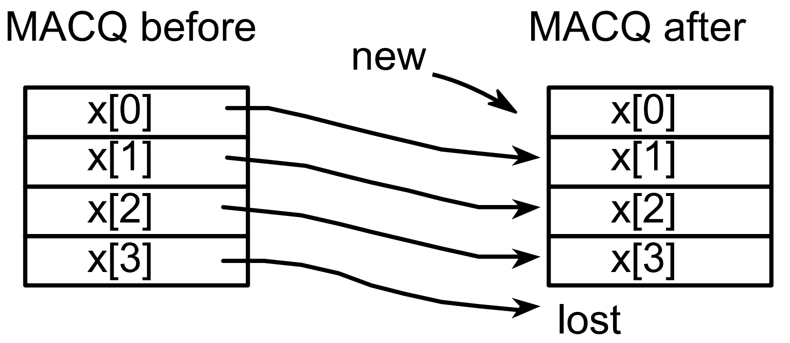
4) Adjust the resistors to maintain the cutoff frequency

$R = 10k\Omega \cdot x$ (10k, $f_c = 51$ Hz)

See https://www.ti.com/design-tools/signal-chain-design/webench-filters.html

Digital Filtering

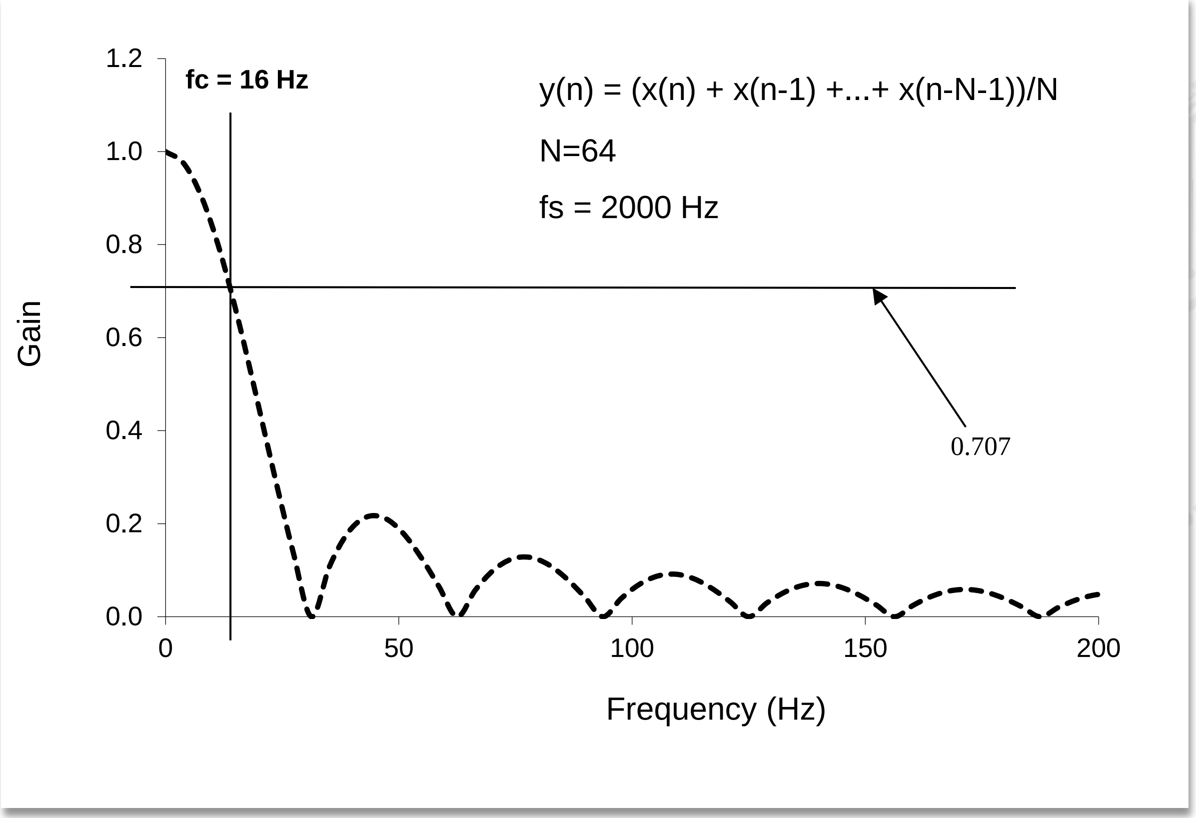
$$y(n) = (x(n)+x(n-1)+x(n-2)+x(n-3)/4$$



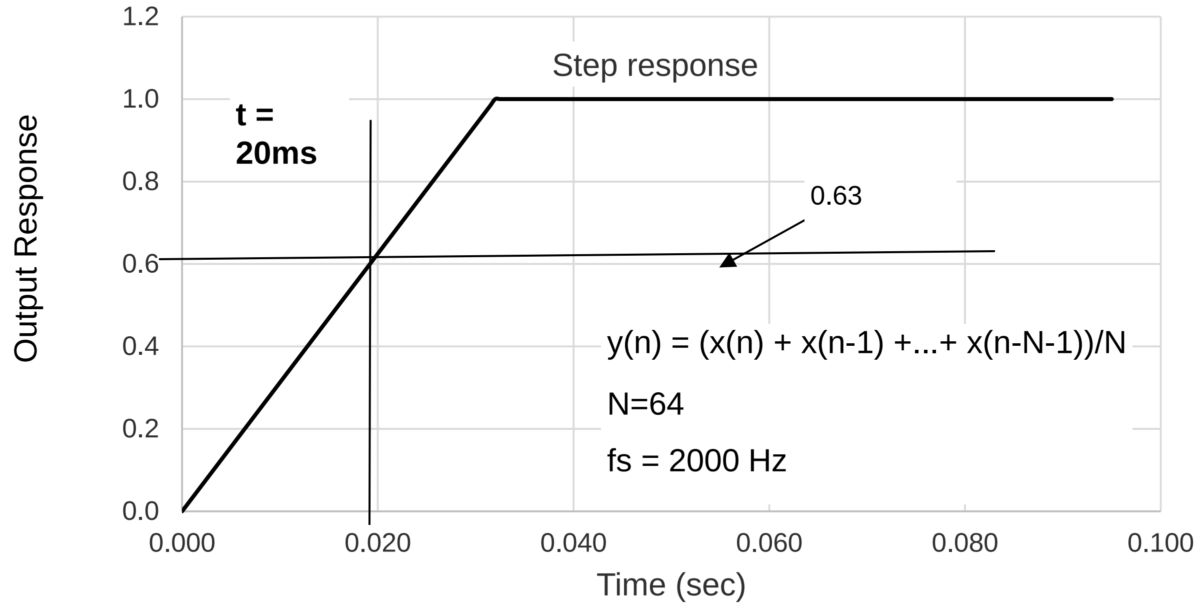

```
x[3] = x[2];
x[2] = x[1];
x[1] = x[0];
x[0] = ADC_In6();
y = (x[0]+x[1]+x[2]+x[3])/4;
```

Averaging Low Pass Filters

- Linear Filter
- Finite Impulse Response
- Low pass



Averaging Low Pass Filters

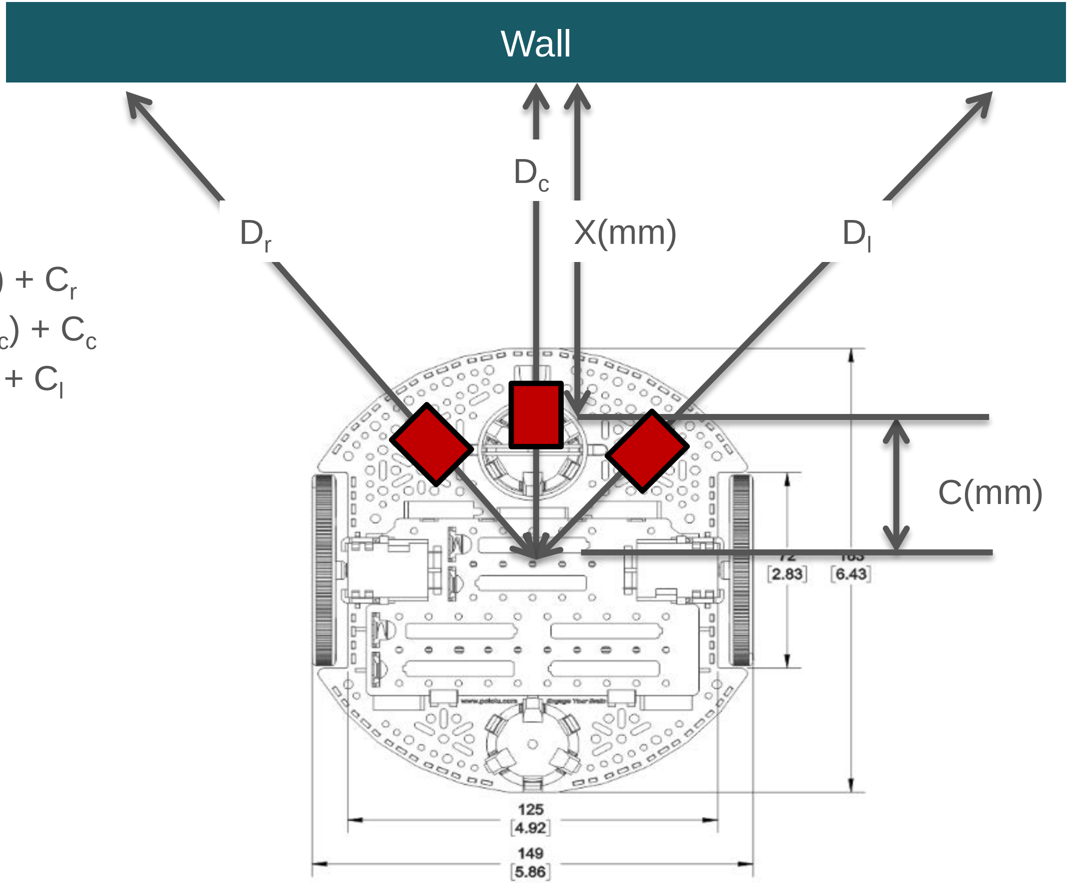


Distance to wall

$\mathbf{D_r} = A_r/(\mathbf{n_r} + B_r) + C_r$

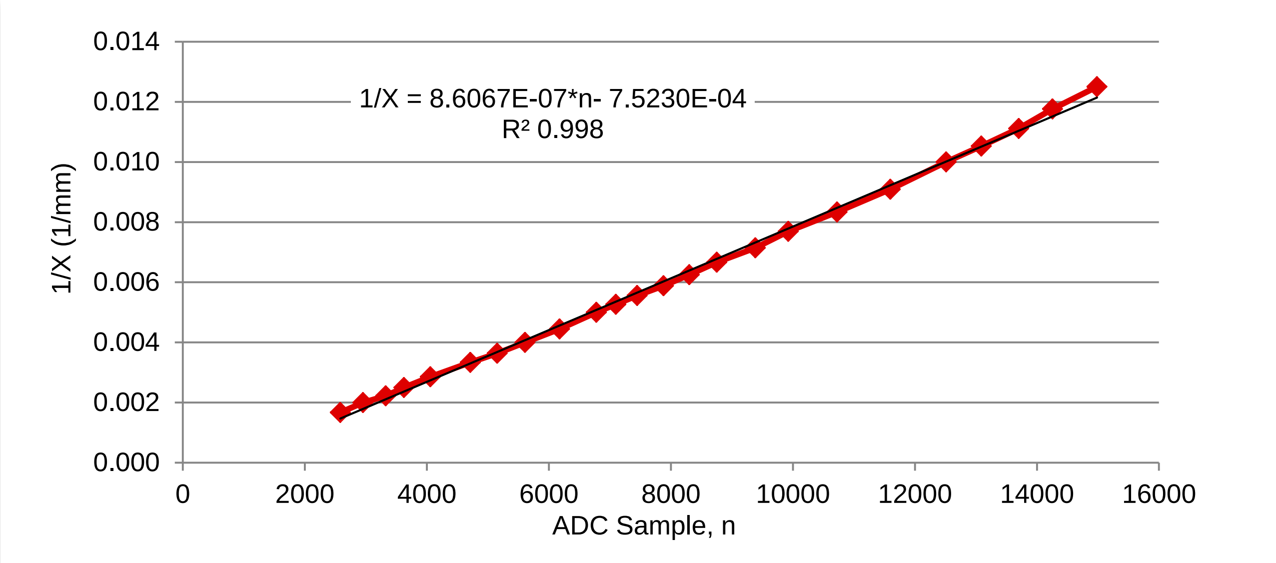
$\mathbf{D_c} = A_c/(\mathbf{n_c} + B_c) + C_c$

$\mathbf{D_l} = A_l/(\mathbf{n_l} + B_l) + C_l$



Calibration

- Distance, X, from the sensor to wall, 80 to 400mm
- ADC value, n
- Linear fit 1/X versus n
- Solve for X = A/(n+B)
- Add distance to central point, D = A/(n+B)+C



Summary

Analog to Digital Converter

- Noise

Sampling

- Nyquist Theorem, Aliasing
- Central Limit Theorem

Filters

- Analog LPF
- Digital LPF

Data Acquisition Systems

- Calibration
- Accuracy

$$\frac{100}{n}\sum_{i=0}^{n}\frac{\left|x_{ti}-x_{mi}\right|}{x_{t\max}}$$

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