

# TI-RSLK

Texas Instruments Robotics System Learning Kit



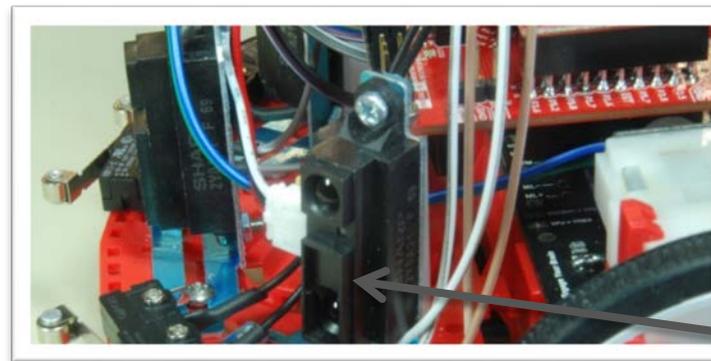
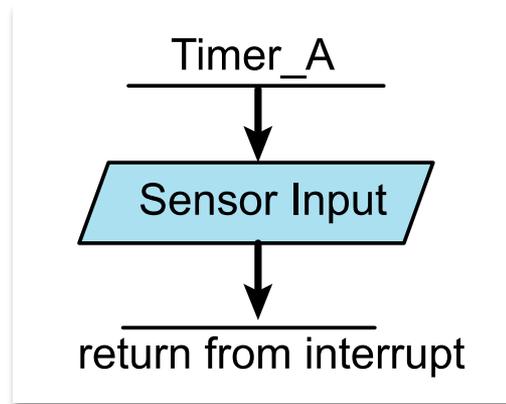
TEXAS INSTRUMENTS

# Module 15

Lecture: Data Acquisition Systems - Theory

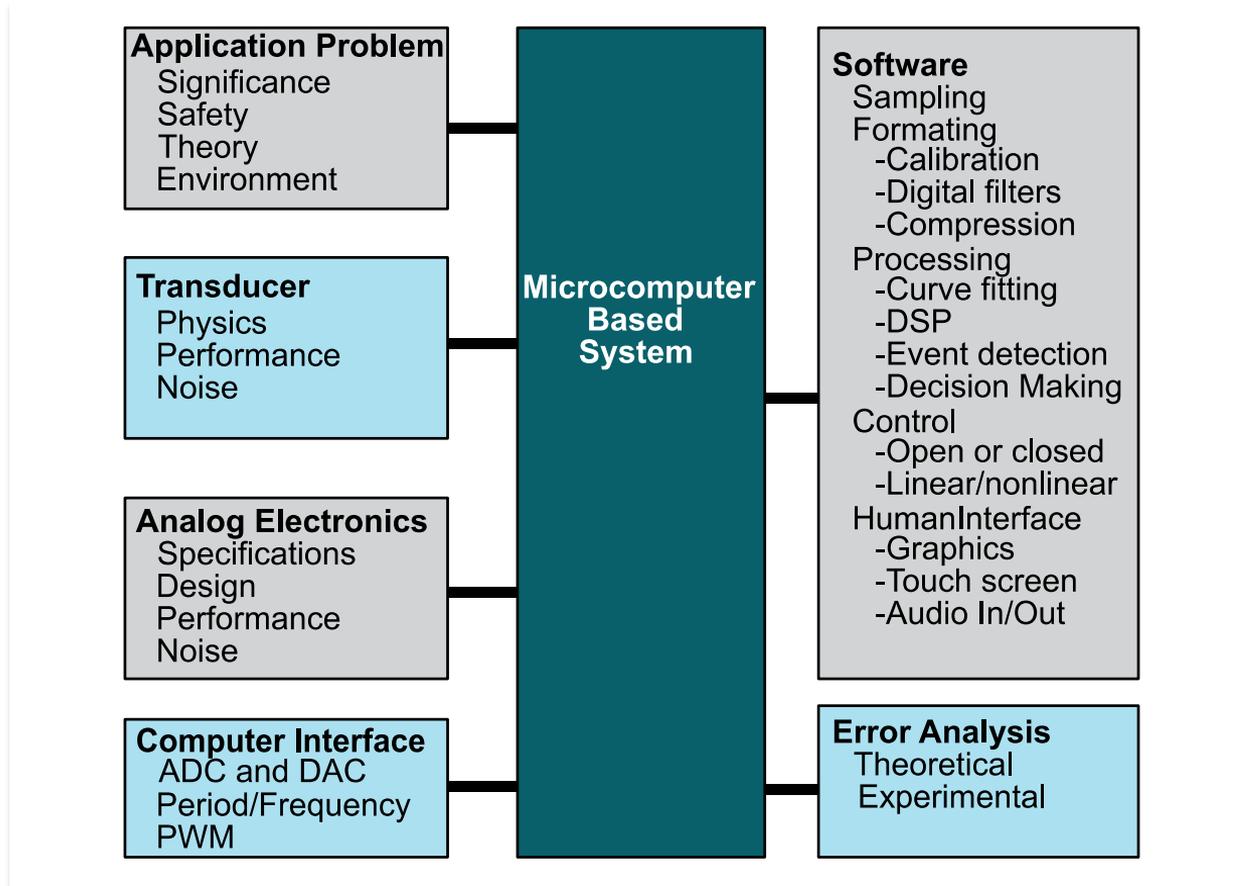
## You will learn in this module

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

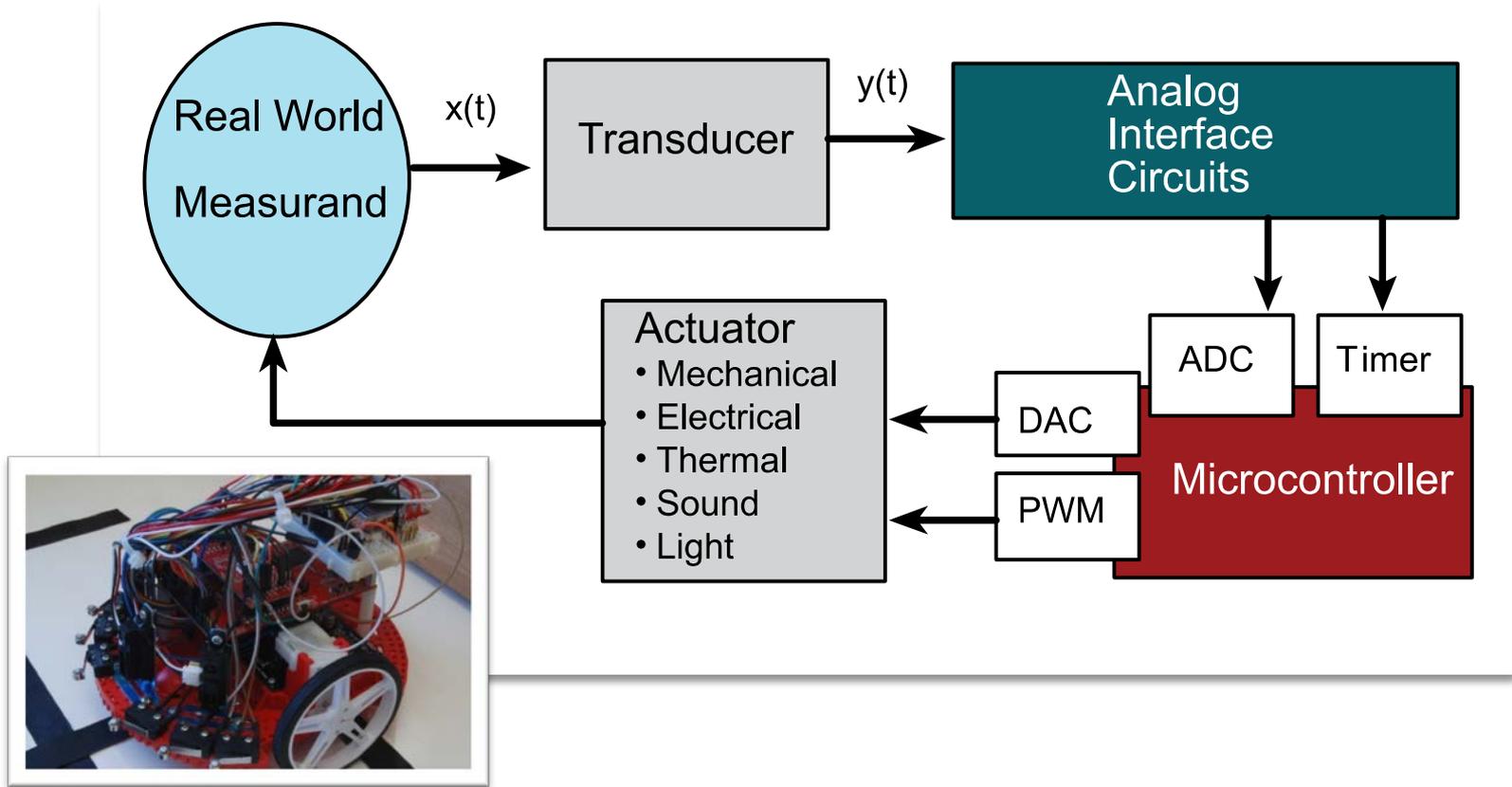


IR Sensor

# Data Acquisition Systems



# A Control System includes a Data Acquisition System



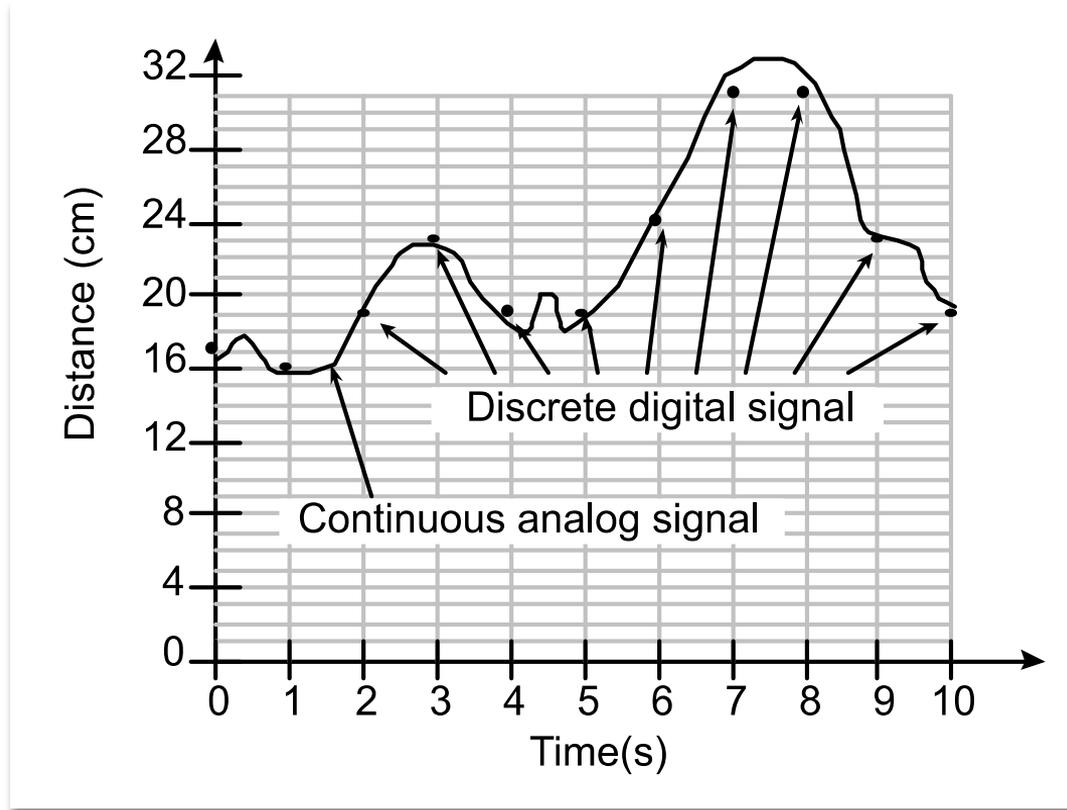
# Sampling: conversion from analog to digital

## Amplitude

- Range
- Resolution
- Precision

## Time domain

- Sampling rate,  $f_s$ 
  - 0 to  $\frac{1}{2} f_s$
- Number of samples
  - Buffer size  $N$
- Frequency resolution
  - $f_s/N$





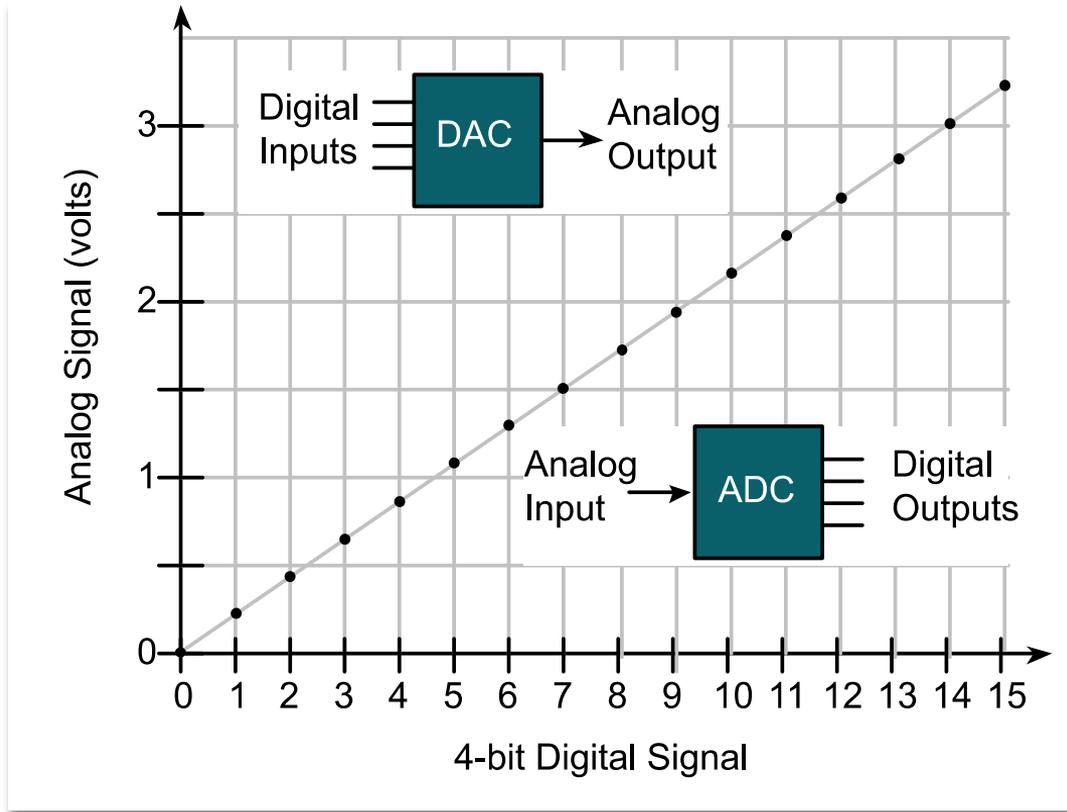
# DAC versus ADC

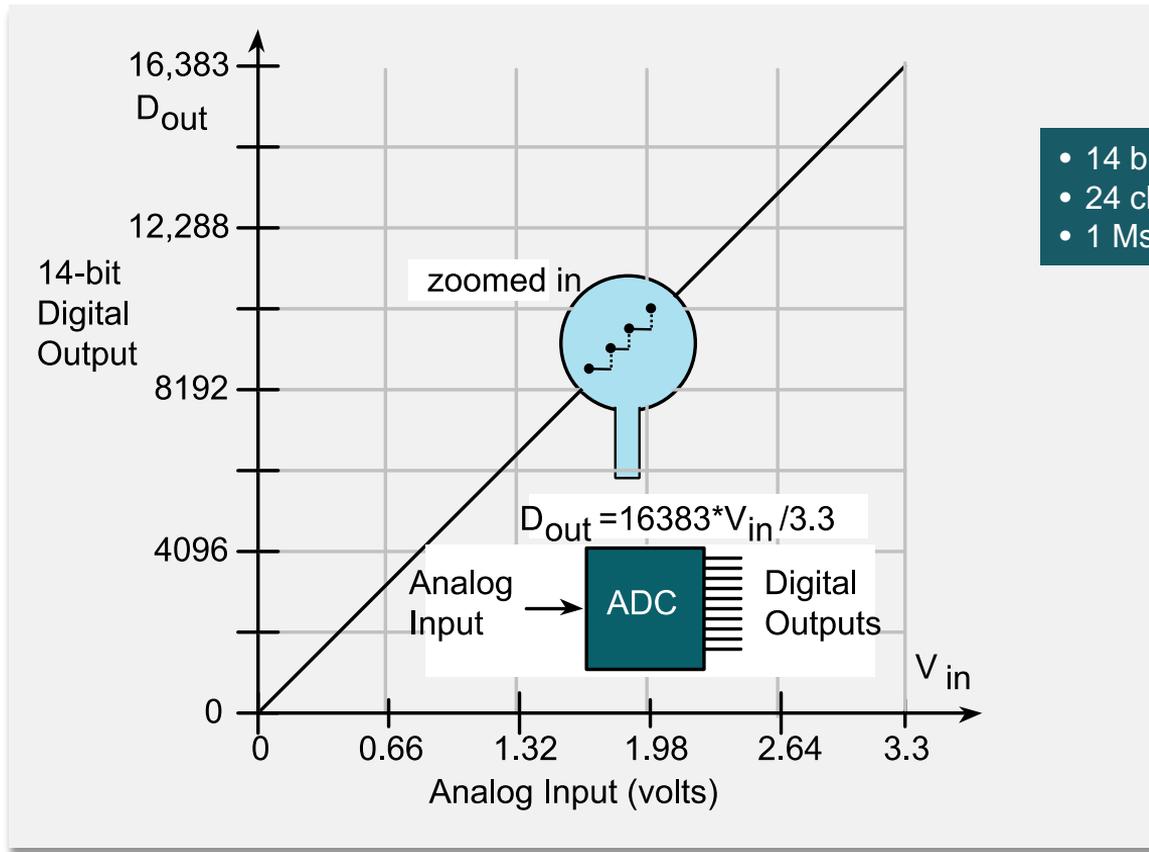
## DAC

- Digital to Analog
- uC output
- Signal generation

## ADC

- Analog to Digital
- uC input
- Measurements





- 14 bits
- 24 channels
- 1 Msp/s



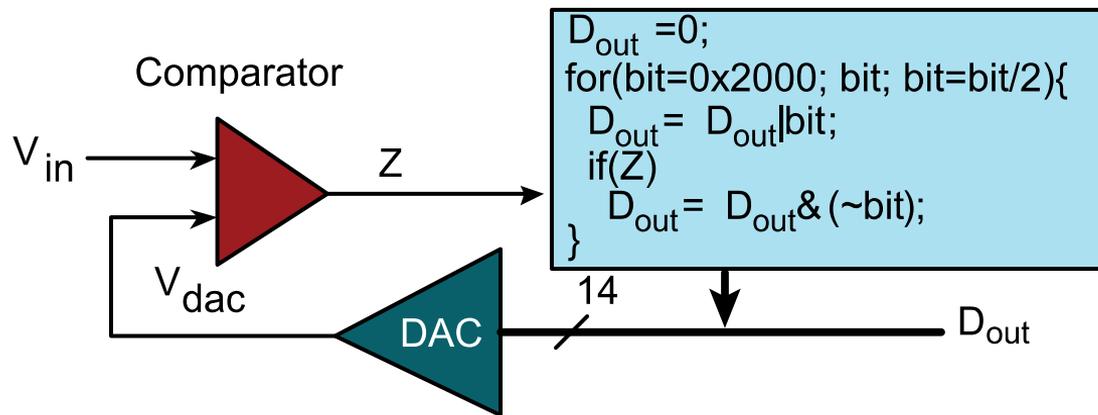
# Successive Approximation

## 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



## 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](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->CTL0

31-30	29-27	26	25	24-22	21-19	18-17	16
PDIV	SHS <sub>x</sub>	SHP	ISSH	DIV <sub>x</sub>	SSEL <sub>x</sub>	CONS <sub>x</sub>	BUSY
15-12	11-8	7	6-5	4	3-2	1	0
SHT1 <sub>x</sub>	SHT0 <sub>x</sub>	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



- Address
- Resolution
- Format
- Power

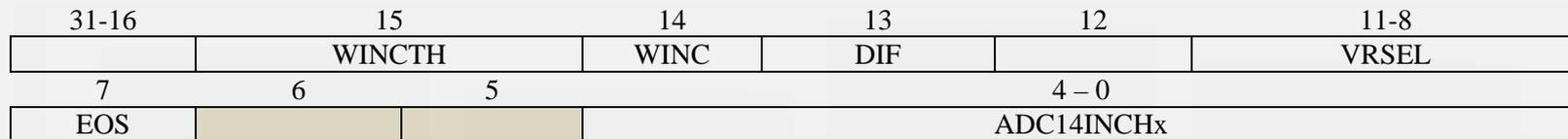
## ADC14->IFGR0



- Conversion complete

# ADC14 Software Initialization

ADC->MCTL[n]



- 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;  
}
```



9 $\mu$ s

# Summary

## Analog to Digital Converter

- Successive Approximation
- Range
- Resolution
- Precision

## Software

- Initialization
- Mailbox

$$\frac{100}{n} \sum_{i=0}^n \frac{|x_{ti} - x_{mi}|}{x_{tmax}}$$



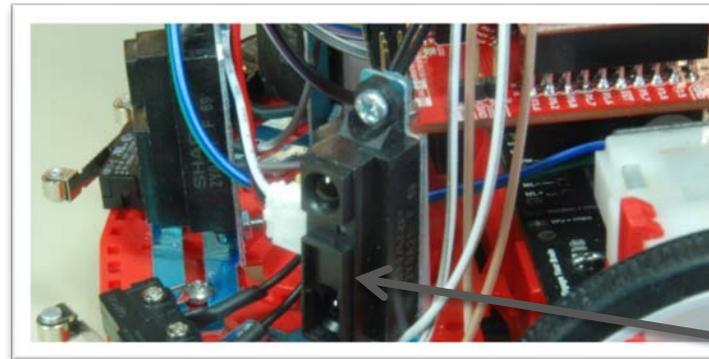
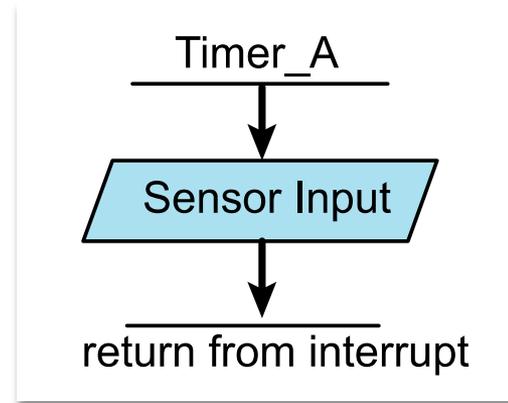
# Module 15

Lecture: Data Acquisition Systems – Performance Measurements

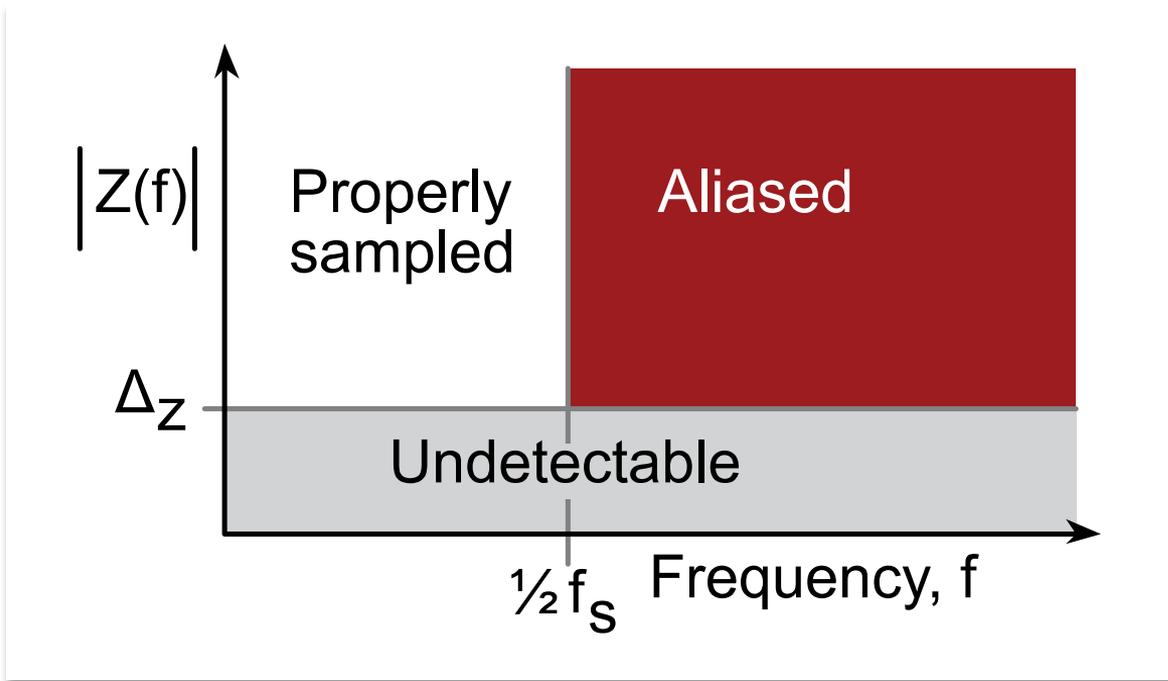
# Data Acquisition Systems

## 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

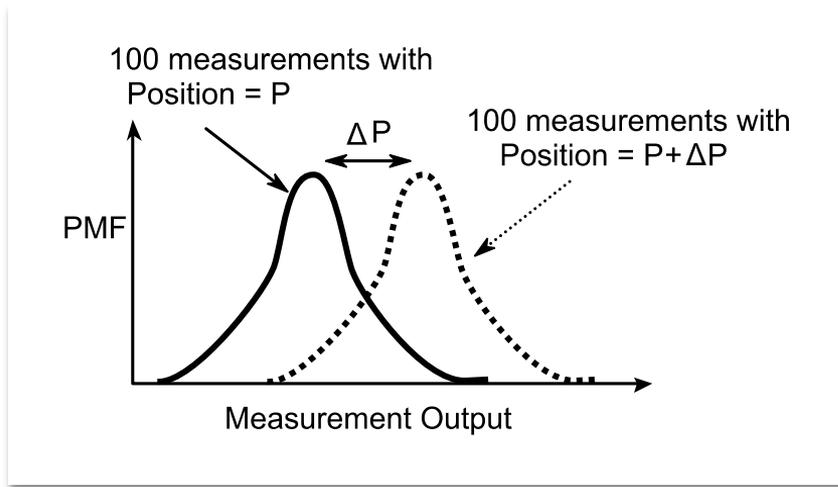


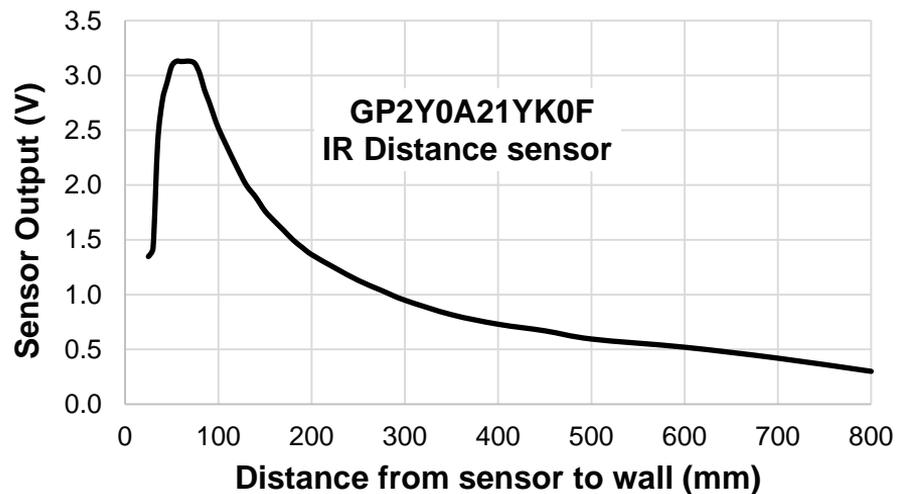
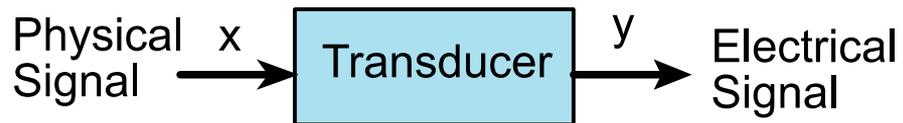
IR Sensor



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  $\frac{1}{2} f_s$ .

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

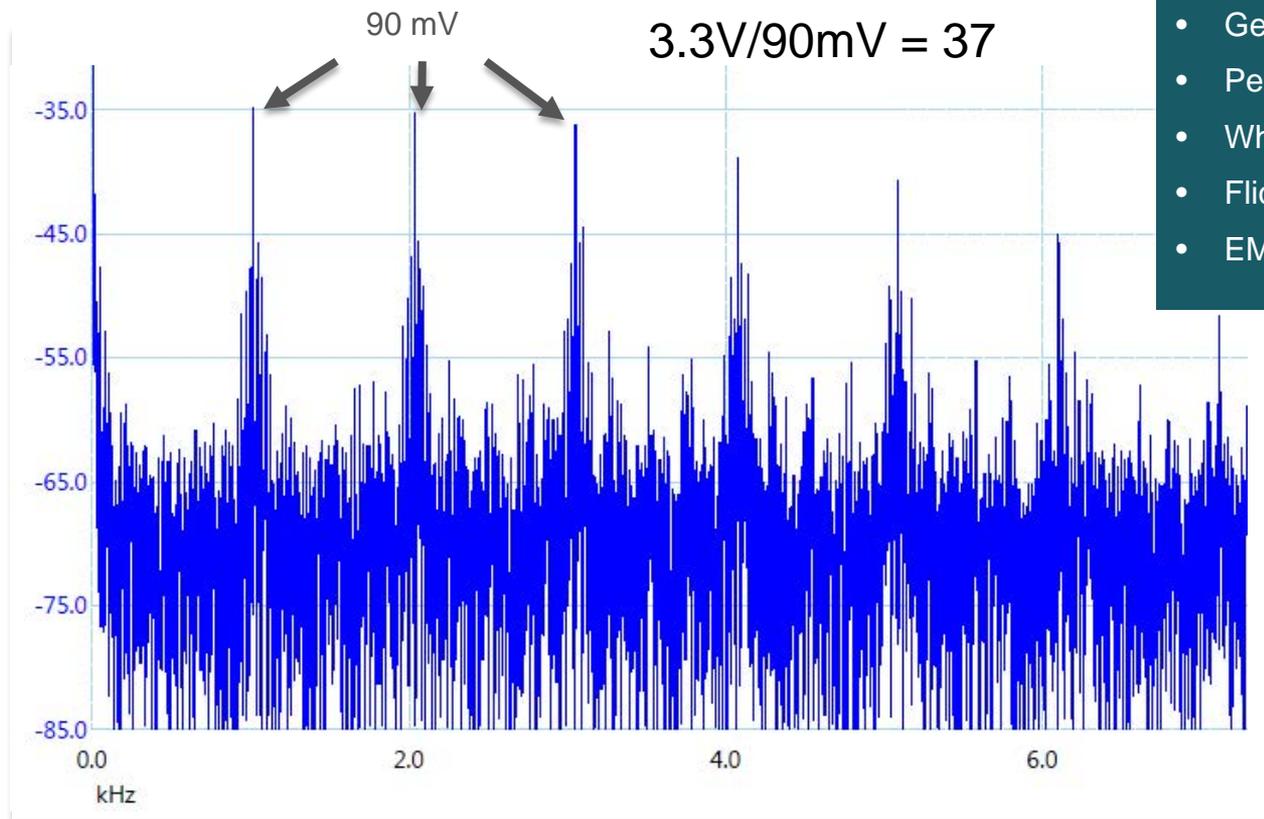




- Nonmonotonic
- Hyperbolic
- Noisy



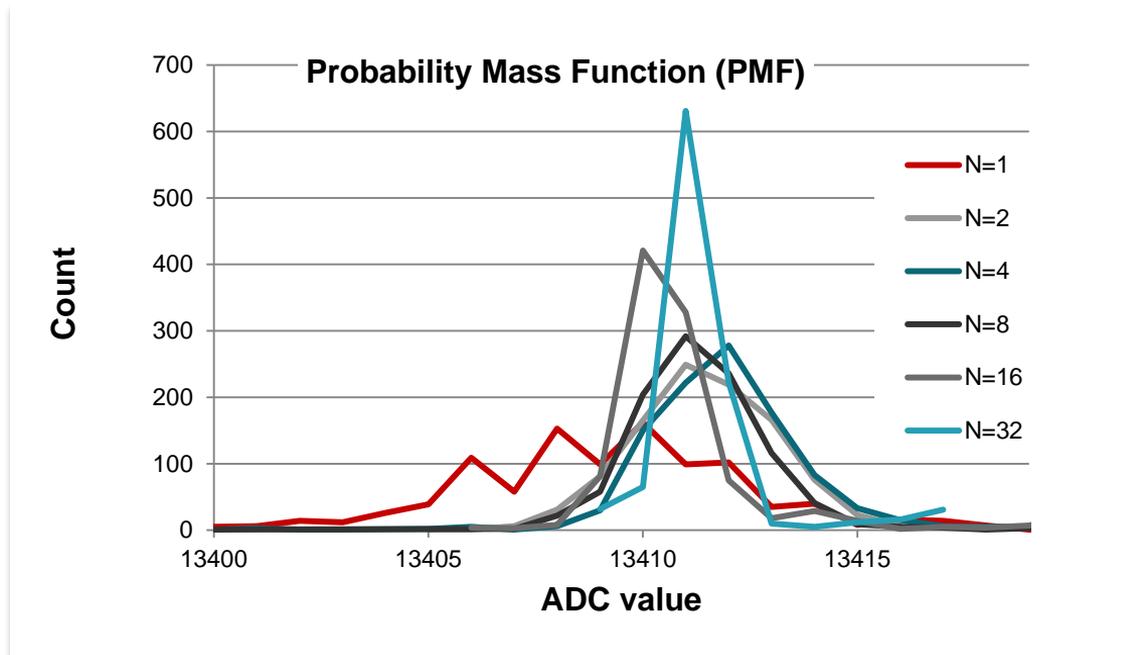
# GP2Y0A21YK0F IR distance sensors are noisy



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

50 Hz analog LPF  
16 Hz digital LPF

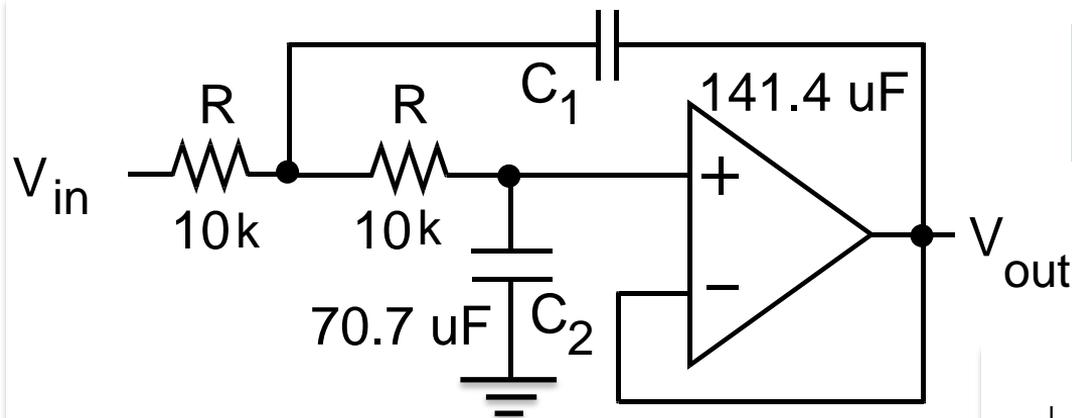
# Probability Mass Function (PMF)



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

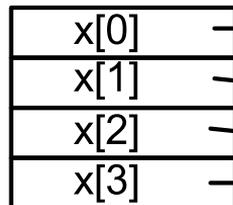
$$\left| \frac{V_{out}}{V_{in}} \right| = \sqrt{\frac{1}{1 + (f / f_c)^4}}$$

- 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)
  - $C_{1A} = 141.4\mu\text{F}/2\pi f_c$  (0.45 $\mu\text{F}$ )
  - $C_{2A} = 70.7\mu\text{F}/2\pi f_c$  (0.225 $\mu\text{F}$ )
- 3) Locate two standard value capacitors (with the 2/1 ratio)
  - $C_{1B} = C_{1A}/x$  (0.44 $\mu\text{F}$ , two 0.22  $\mu\text{F}$  in parallel)
  - $C_{2B} = C_{2A}/x$  (0.22 $\mu\text{F}$ )
- 4) Adjust the resistors to maintain the cutoff frequency
  - $R = 10\text{k}\Omega \cdot x$  (10k,  $f_c = 51$  Hz)

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

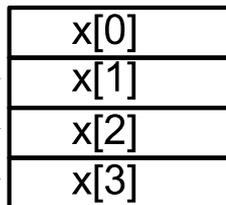
$$y(n) = (x(n)+x(n-1)+x(n-2)+x(n-3))/4$$

MACQ before



new

MACQ after

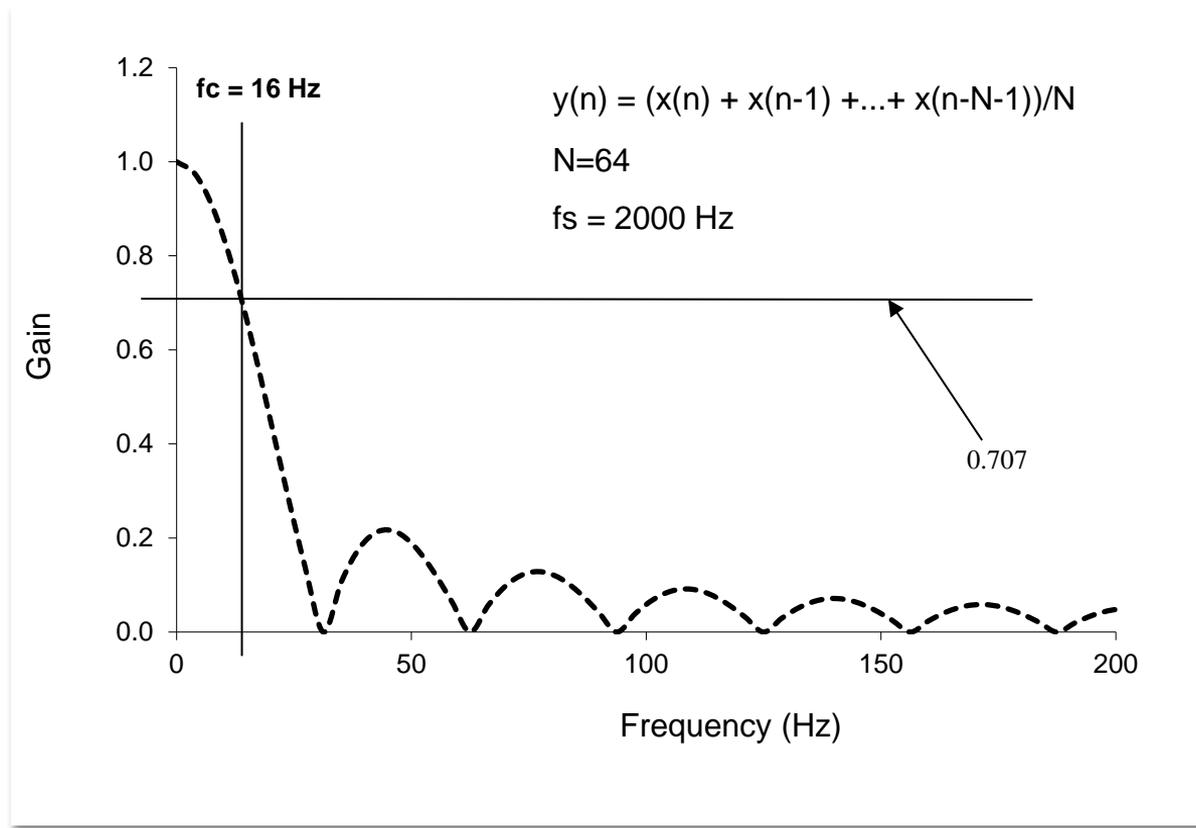


lost

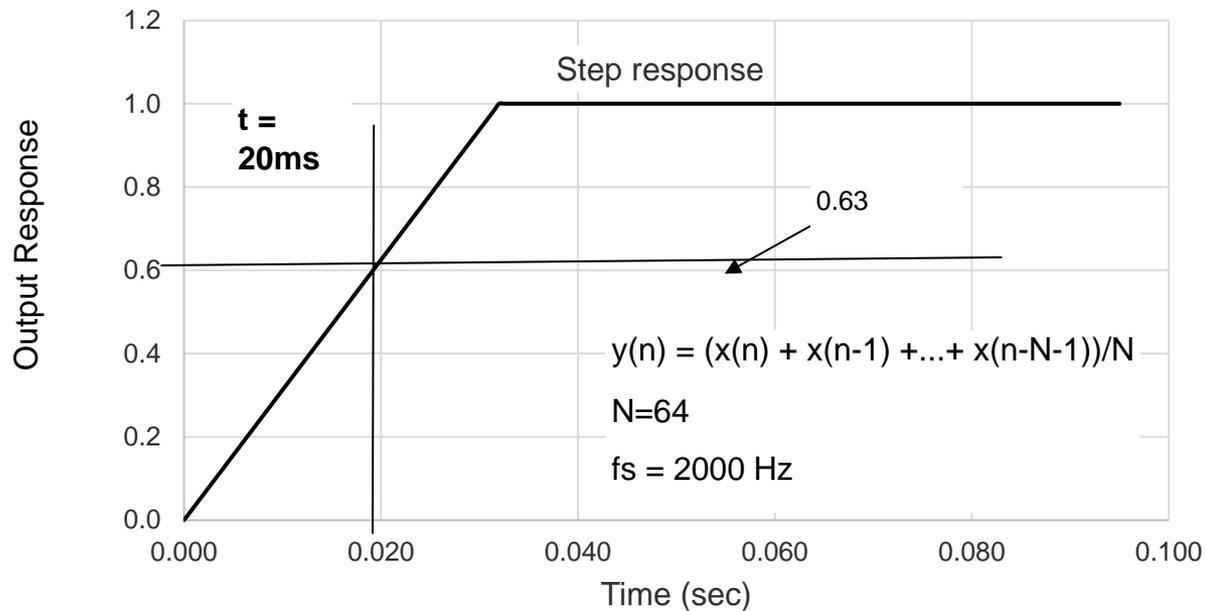
```
x[3] = x[2];
x[2] = x[1];
x[1] = x[0];
x[0] = ADC_In6();
y = (x[0]+x[1]+x[2]+x[3])/4;
```

# Averaging Low Pass Filters

- Linear Filter
- Finite Impulse Response
- Low pass



# Averaging Low Pass Filters

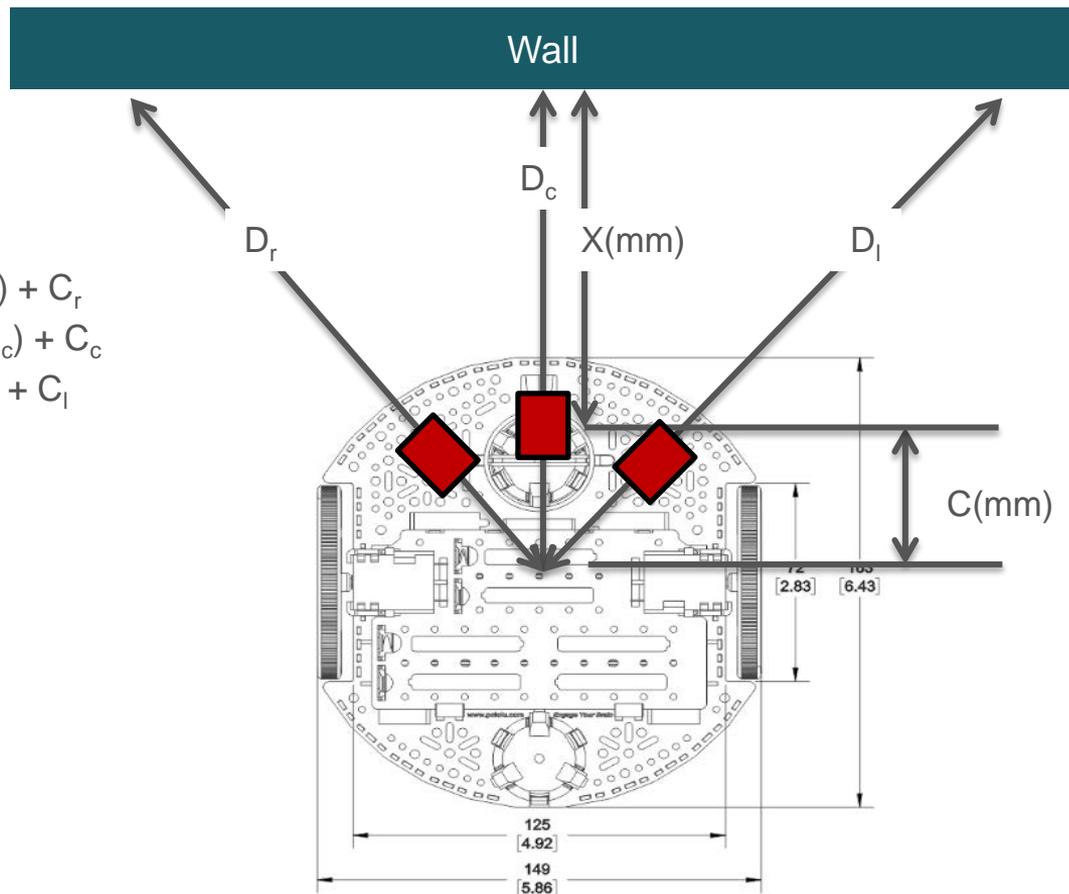


# Distance to wall

$$D_r = A_r / (n_r + B_r) + C_r$$

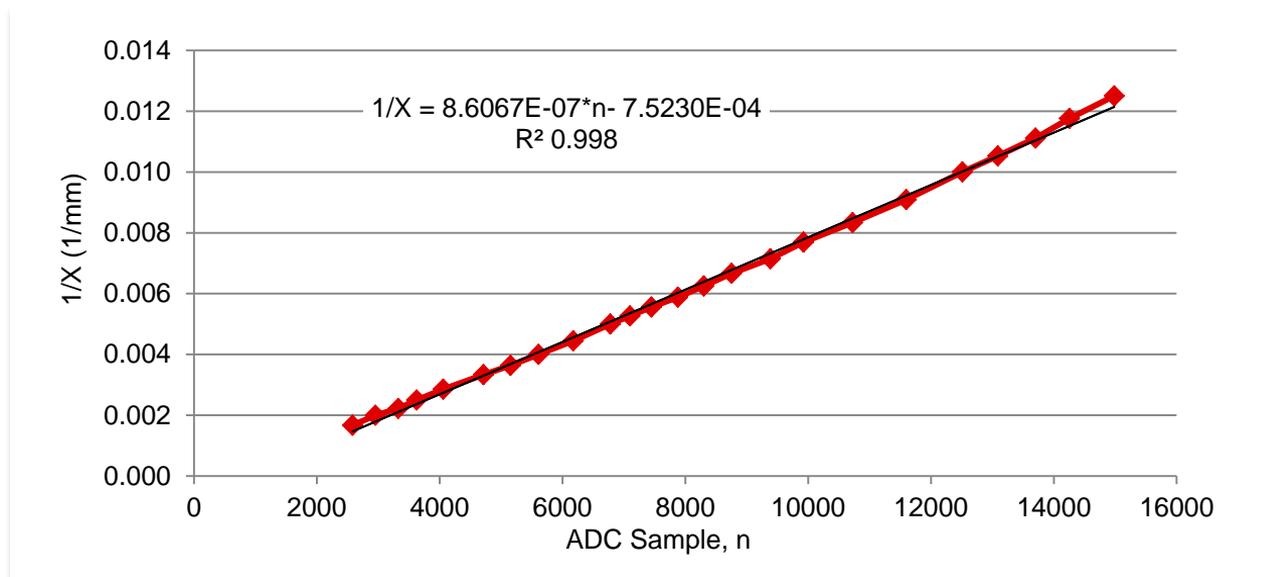
$$D_c = A_c / (n_c + B_c) + C_c$$

$$D_l = A_l / (n_l + B_l) + C_l$$



# 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

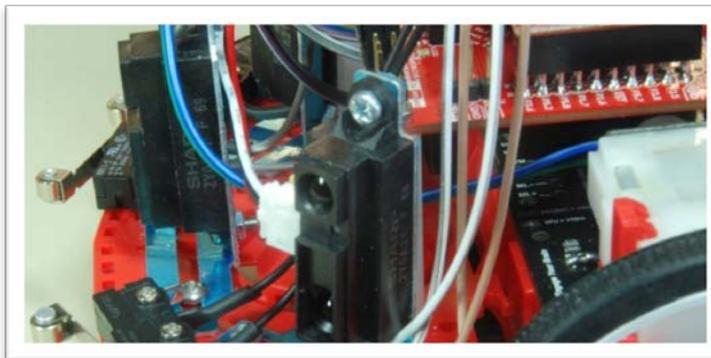
## Filters

- Analog LPF
- Digital LPF

## Data Acquisition Systems

- Calibration
- Accuracy

$$\frac{100}{n} \sum_{i=0}^n \frac{|x_{ti} - x_{mi}|}{x_{tmax}}$$



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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
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