Sensors, Errors, A2D Theory and Sampling

CENG 5437, CENG 4391 SPRING 2023

SENSORS **Sampling and A2D**

Classes of Sensors Characterization of Sensors

Connect Sensors to the Computer – A2D converters, etc.
RESOLUTION VS. ACCURACY

Accuracy and errors: Types of Errors – Statistical and Random

Odometry Errors - Example

Sampling Theory and Video Aliasing

Navigation Errors for Moving Robot

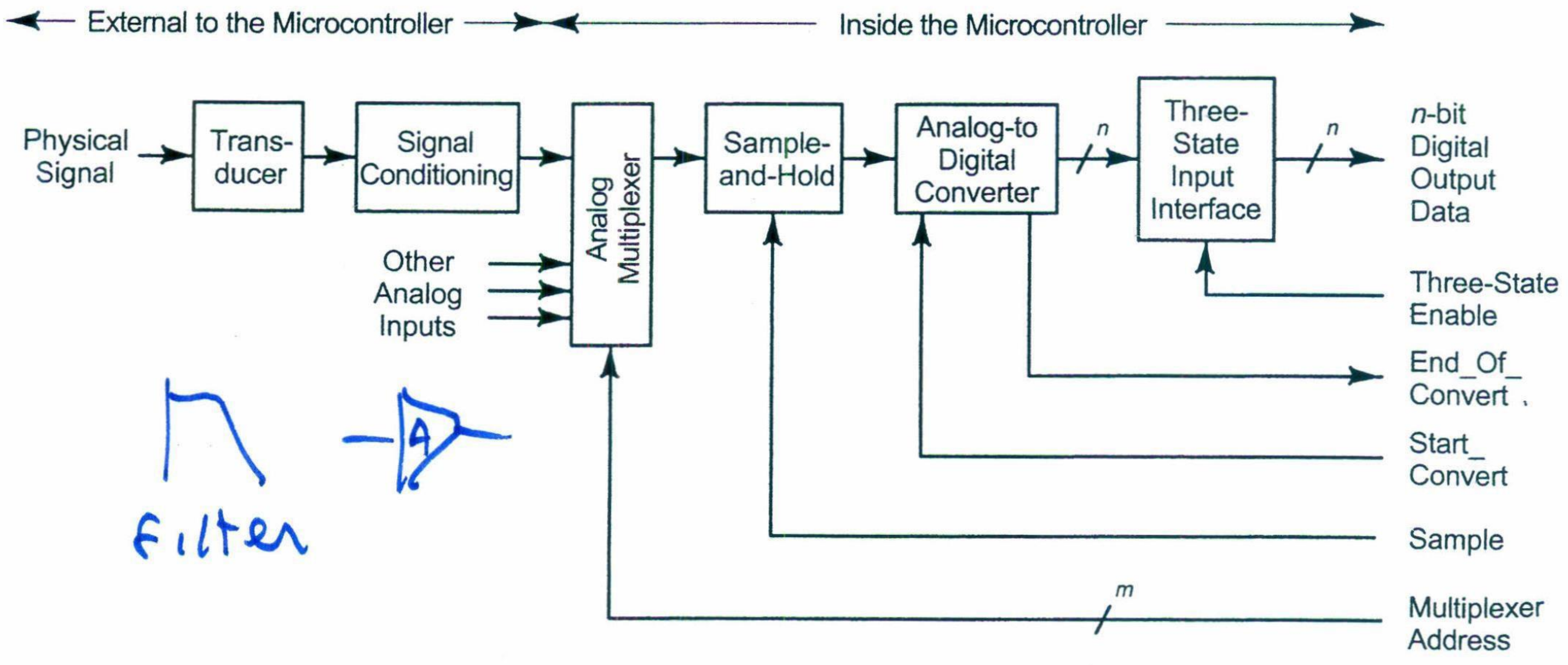


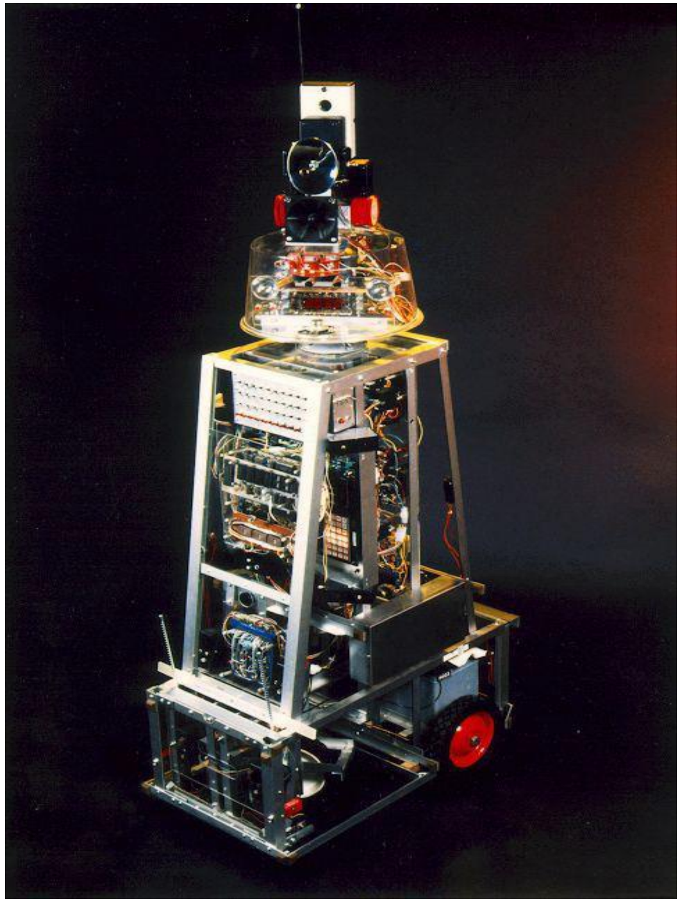
Figure 13-1 Data acquisition system.

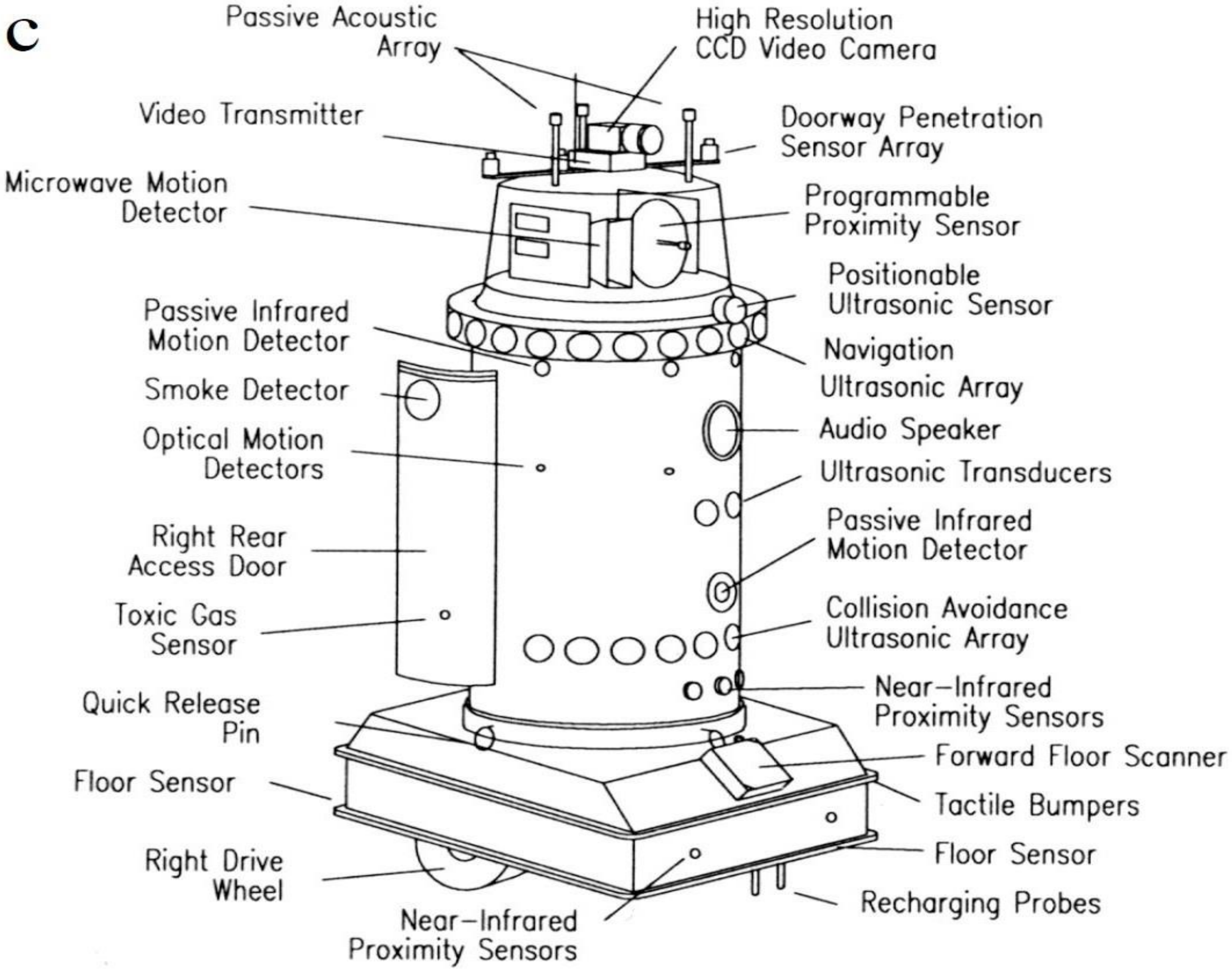
Sensors

- **Proprioceptive Sensors**
  (monitor state of robot)
  - IMU (accels & gyros)
  - Wheel encoders
  - Doppler radar …

- **Exteroceptive Sensors**
  (monitor environment)
  - Cameras (single, stereo, omni, FL
  - Laser scanner
  - MW radar
  - Sonar
  - Tactile…

1980-82 – ROBART-I Sentry Robot – H. R. Everett





RESOLUTION OF A DIGITAL REGISTER OR A2D CONVERTER

https://spectrum-instrumentation.com/support/knowledgebase/hardware_features/ADC_and_Resolution.php

Digitizers convert the samples of an analog signal into digital values using analog to digital converters (ADCs). The **resolution of the ADC is the number of bits it uses to digitize the input samples.**

For an n bit ADC the number of discrete digital levels that can be produced is 2^n. Thus, a 12 bit digitizer can resolve 2^12 or 4096 levels.

The least significant bit (lsb) represents the smallest interval that can be detected and in the case of a 12 bit digitizer is 1/4096.

To convert the lsb into a voltage, we take the input range of the digitizer and divide by 2 raised to the resolution of the digitizer.

Table 1 shows the lsb for a 1 Volt input range for digitizers with resolutions of 8 to 16 bits.

Digitizer step size vs. resolution

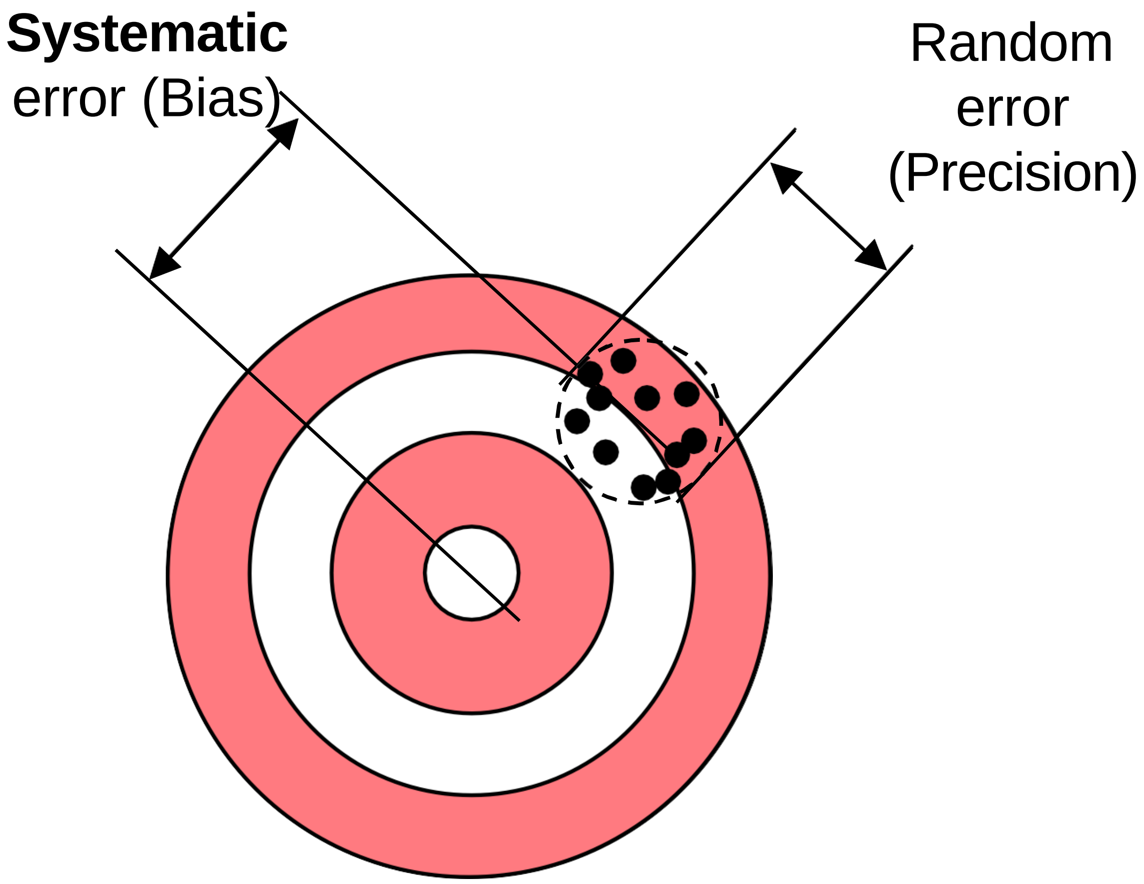
8 Bit	256:1	3.92 mV
10 Bit	1024:1	0.98 mV
12 Bit	4096:1	0.244 mV
14 Bit	16384:1	61 µV
16 Bit	65536:1	15 µV

Resolution determines the precision of a measurement. (NOT THE ACCURACY)! The greater the digitizer resolution, the more **precise** the measurement values.

A digitizer with an 8-bit ADC divides the vertical range of the input amplifier into 256 discrete levels. With a vertical range of 1 V, the 8 bit ADC cannot ideally resolve voltage differences smaller than 3.92 mV; while a 16 bit ADC, with 65,656 discrete levels, can ideally resolve voltage differences as small as 15 µV.

DO NOT CONFUSE THIS WITH ACCURACY!!!

Example: systematic and random errors



Accuracy and errors

- **Systematic errors**
  - Result from a variety of factors
    - Interfering or modifying variables (i.e., temperature)
    - Drift (i.e., changes in chemical structure or mechanical stresses)
    - The measurement process changes the measurand (i.e., loading errors)
    - The transmission process changes the signal (i.e., attenuation)
    - Human observers (i.e., parallax errors)
  - **Systematic errors can be corrected with COMPENSATION methods (i.e., feedback, filtering)**
- **Random errors**
  - Also called NOISE: a signal that carries no information
  - True random errors (white noise) follow a Gaussian distribution
  - Sources of randomness:
    - Repeatability of the measurand itself (i.e., height of a rough surface)
    - Environmental noise (i.e., background noise picked by a microphone)
    - Transmission noise (i.e., 60Hz hum)
  - Signal to noise ratio (SNR) should be >>1
    - With knowledge of the signal characteristics it may be possible to interpret a signal with a low SNR (i.e., understanding speech in a loud environment)

• **Resolution:** Resolution is the minimum step size within the range of measurement of the sensor. In a wire-wound potentiometer, it will be equal to the resistance of one turn of the wire. In a digital device with *n* bits, the resolution will be

$$\text{Resolution} = \text{Full Range}/\ 2^n$$

For example, an absolute encoder with 4 bits can report positions up to $2^4 = 16$ different levels. Thus, its resolution is $360/16 = 22.5°$.

Accuracy: Accuracy is defined as how close the output of the sensor is to the expected value. If for a given input, the output is expected to be a certain value, the accuracy is related to how close the sensor's output is to this value.

1. Measurement and Correction of Systematic Odometry Errors in Mobile Robots

By **Johann Borenstein and Liqiang Feng**

(It would be difficult to get more information on Odometry)

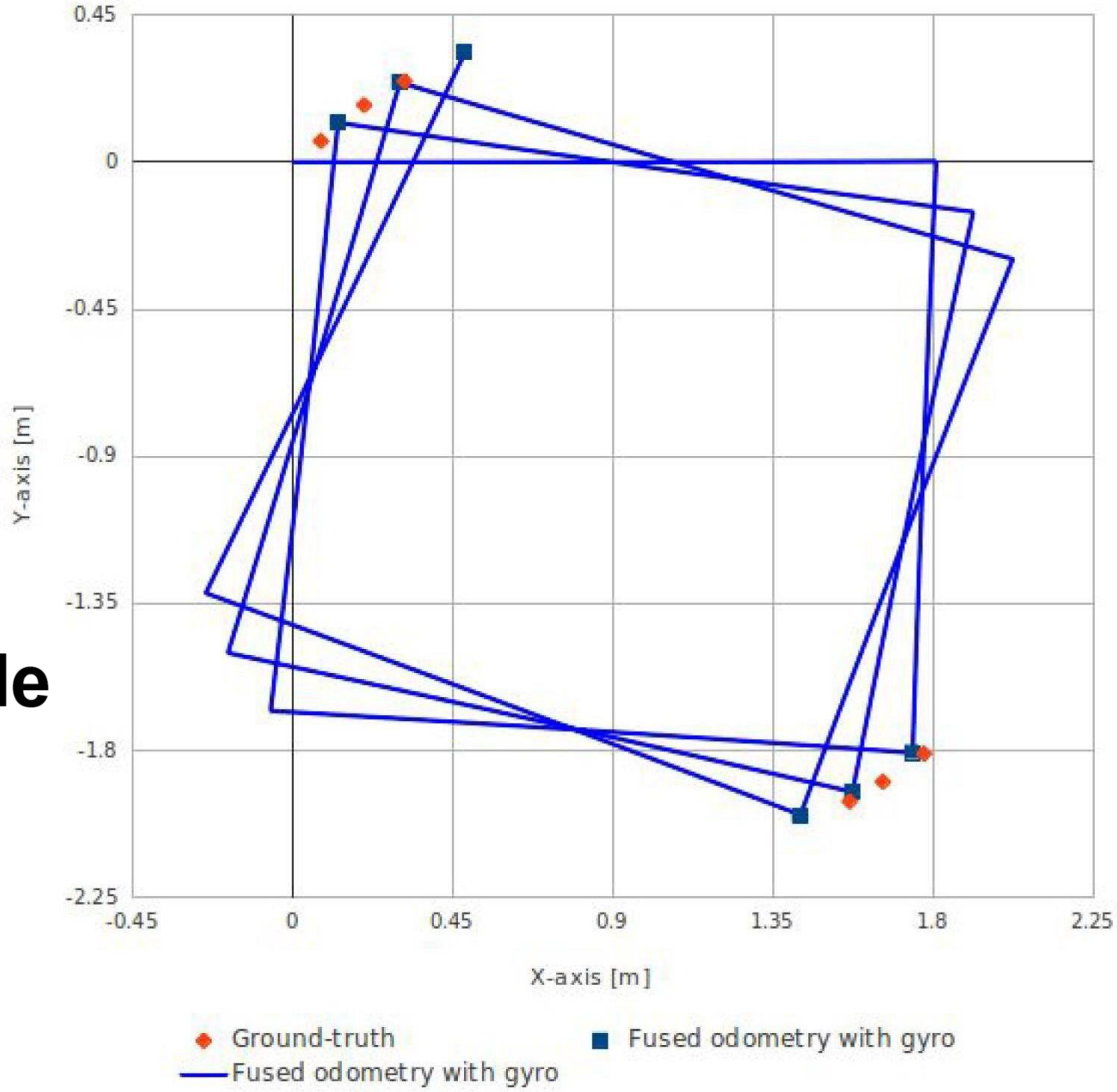
http://www-personal.umich.edu/~johannb/Papers/paper58.pdf

THERE IS HOPE TO ELIMINATE (REDUCE) THE SYSTEMATIC ERRORS BY CALIBRATION!

REDUCING RANDOM ERRORS FROM THE SENSORS IS ANOTHER STORY!
(TO BE TOLD LATER IN COURSE)

ACTUAL PATH ?

Kobuki User Guide



This graph shows the position error of fused odometry with gyro, when robot moves along a square path. Robot moved with 0.1 m/s on the line segment and rotated with 30 deg/s on the corner.

CAN WE IMPROVE IT??

MODIFIED TLH

DSP First, 2/e

Sampling & Aliasing

CHAPTER 4 PRESENTATION 2

SAMPLING THEOREM THE BIG DEAL!!

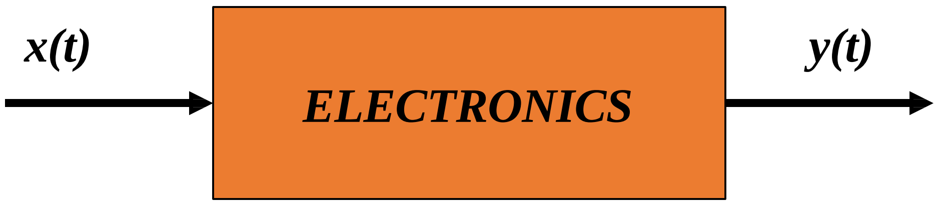
- HOW OFTEN DO WE NEED TO SAMPLE?
  - DEPENDS on FREQUENCY of SINUSOID
  - ANSWERED by SHANNON/NYQUIST Theorem
  - ALSO DEPENDS on "**RECONSTRUCTION**"

Shannon Sampling Theorem

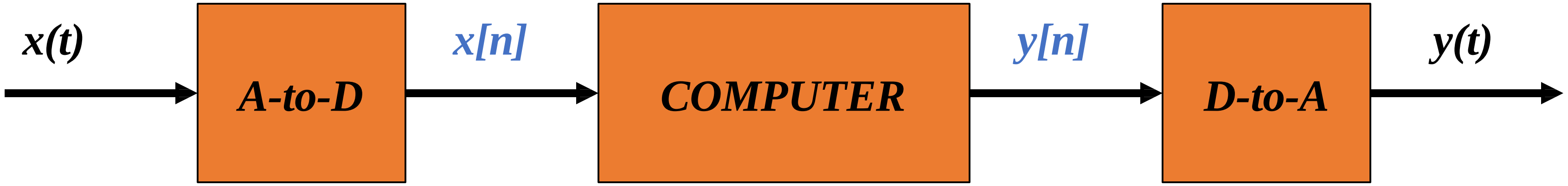
A continuous-time signal $x(t)$ with frequencies no higher than $f_{\max}$ can be reconstructed exactly from its samples $x[n] = x(nT_s)$, if the samples are taken at a rate $f_s = 1/T_s$ that is greater than $2f_{\max}$.

System IMPLEMENTATION

- ANALOG/ELECTRONIC:
  - Circuits: resistors, capacitors, op-amps

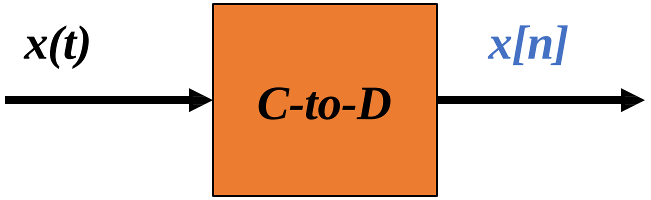


- DIGITAL/MICROPROCESSOR
  - Convert x(t) to numbers stored in memory



SAMPLING x(t)

- SAMPLING PROCESS
  - Convert x(t) to numbers x[n]
  - "n" is an integer index; x[n] is a sequence of values
  - Think of "n" as the storage address in memory
- UNIFORM SAMPLING at $t = nT_s$
  - IDEAL: $x[n] = x(nT_s)$



SAMPLING RATE, f_s

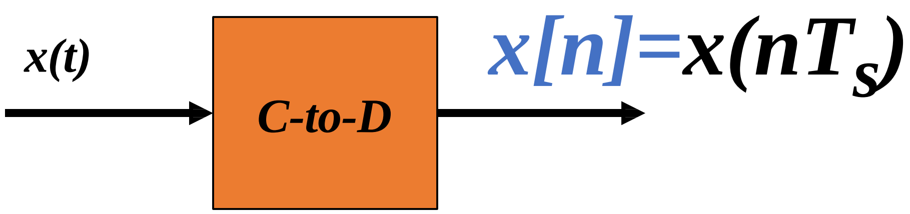
- SAMPLING RATE (f_s)
  - $f_s = 1/T_s$
    - NUMBER of SAMPLES PER SECOND

SOMETIMES GIVEN IN Hz

  - T_s = 125 microsec ➔ f_s = 8000 samples/sec
    - UNITS of f_s ARE HERTZ: 8000 Hz

Thus - Fmax = 4000 Hz

- UNIFORM SAMPLING at $t = nT_s = n/f_s$
  - IDEAL: $x[n] = x(nT_s) = x(n/f_s)$

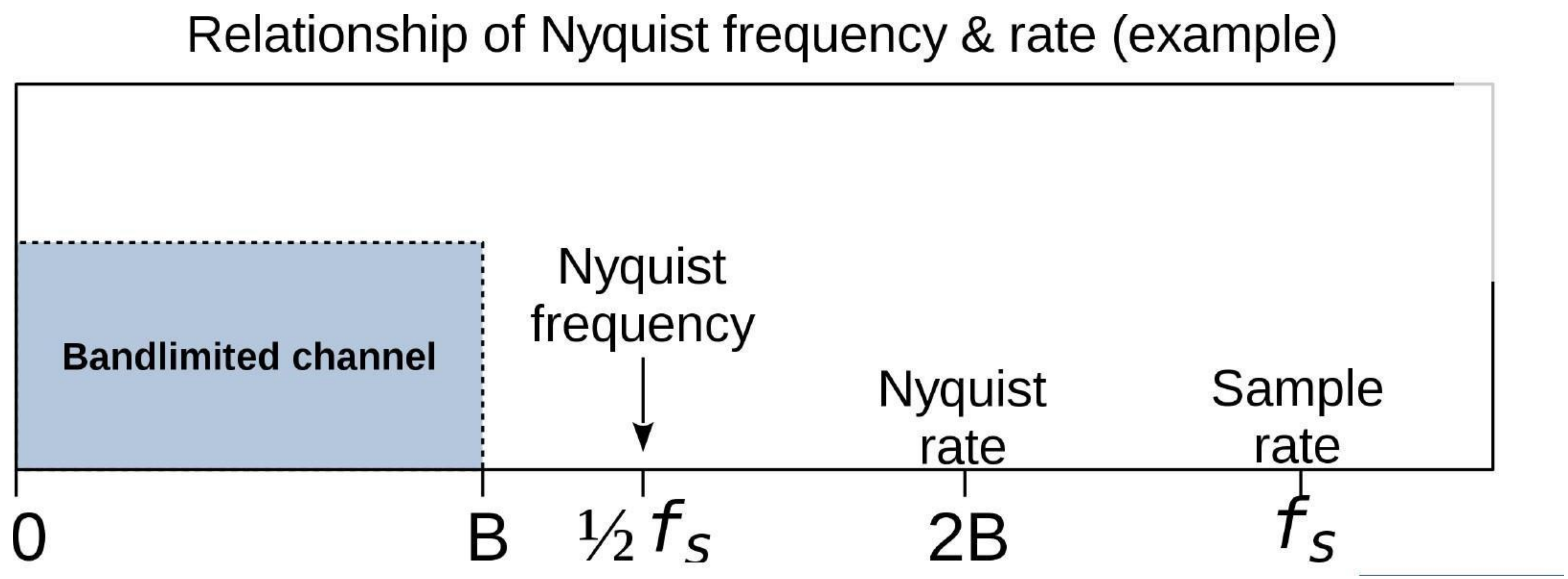


STORING DIGITAL SOUND

- $x[n]$ is a SAMPLED SISIGNAL
  - A list of numbers stored in memory
- EXAMPLE: audio CD
- CD rate is 44,100 samples per second
  - 16-bit samples
  - Stereo uses 2 channels

THUS – Frequency range of 22,050 Hz is beyond (most) humans hearing range.

- Number of bytes for 1 minute is
  - 2 X (16/8) X 60 X 44100 = 10.584 Mbytes



Basic Sampling at 2x Highest Frequency in Band (B)

Nyquist Limit

The absolute limiting resolution of a sensor is determined by its Nyquist limit. This is defined as being one half of the sampling frequency, a.k.a **the number of pixels/mm** (Equation 3). For example, the Sony ICX285 is a monochrome CCD sensor with a horizontal active area of 9mm containing 1392 horizontal pixels each 6.45µm in size. This represents a horizontal sampling frequency of 155 pixels/mm (1392 pixels / 9mm = 1mm / 0.00645 mm/pixel = 155).

SPATIAL SAMPLING

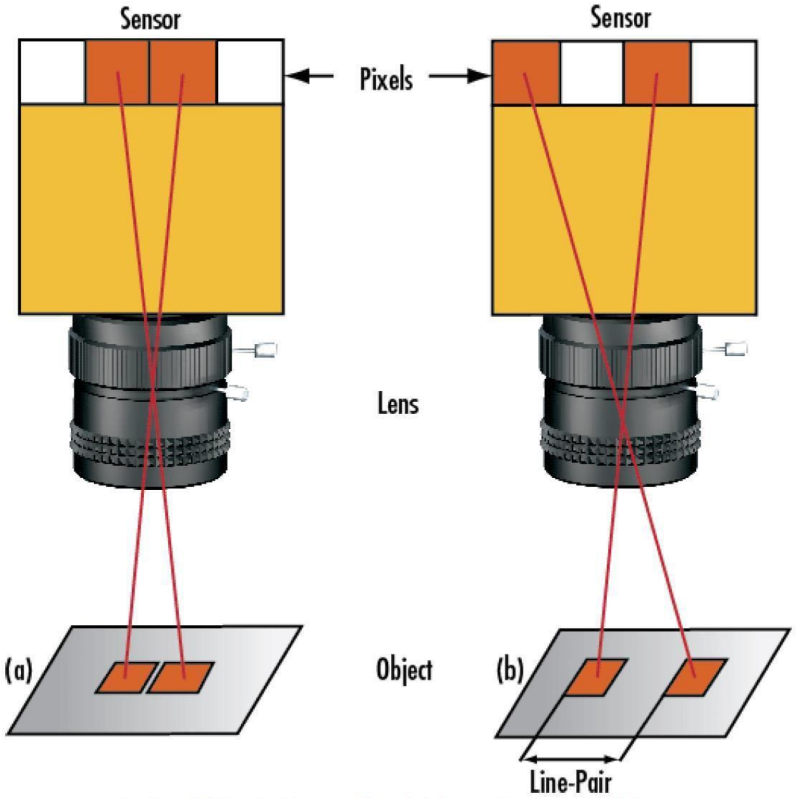


Figure 2: *Pair of Pixels Unresolved (a) vs. Resolved (b)*

Lp = LinePairs

https://www.edmundoptics.com/knowledge-center/application-notes/imaging/camera-resolution-for-improved-imaging-system-performance/

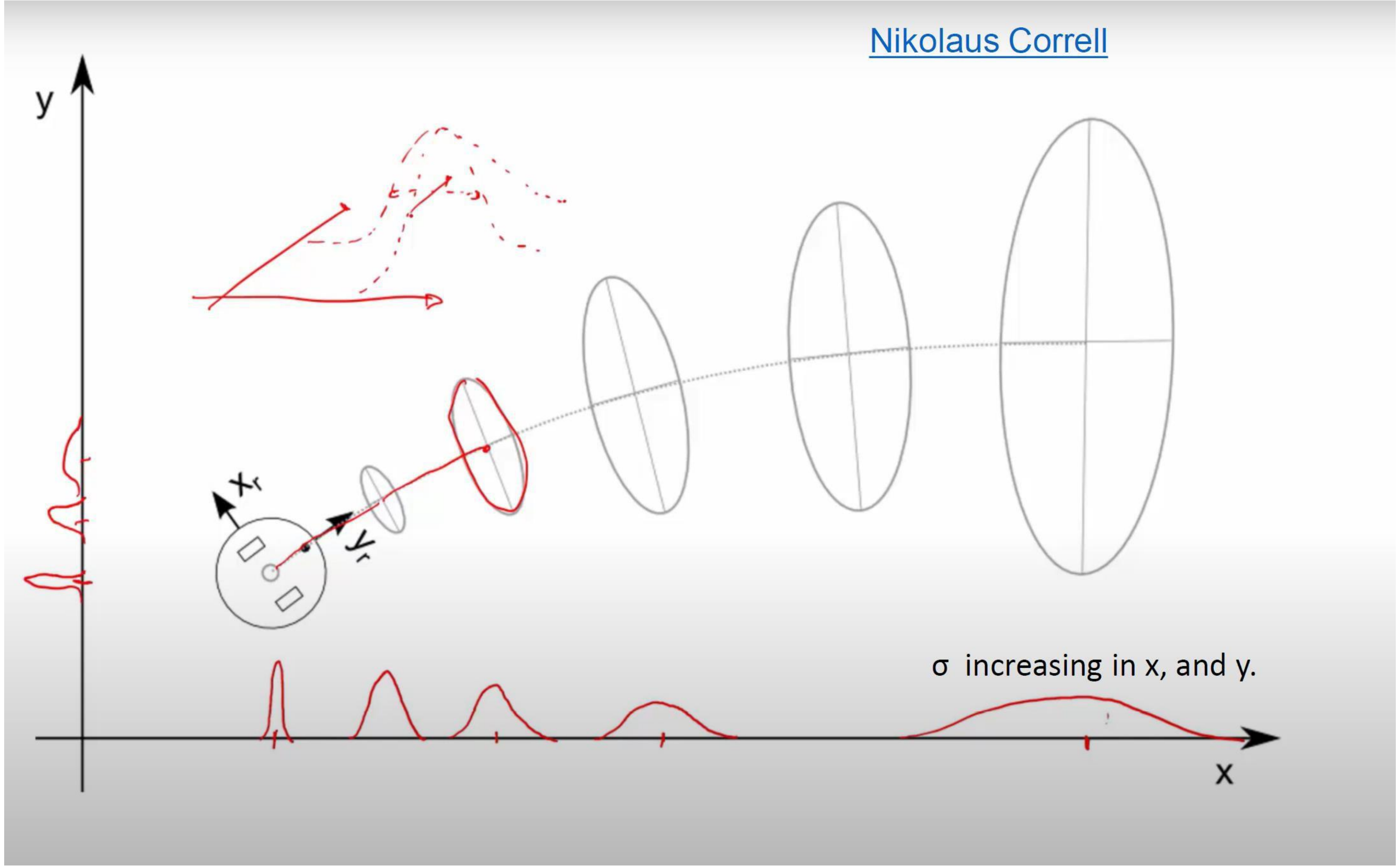
Video Aliasing

Why car wheels rotate backwards in movies 4:25

https://www.youtube.com/watch?v=SFbINinFsxk&feature=youtu.be

INCORRECT SAMPLING LEADS TO "FUNNY THINGS" IN VIDEOS ALSO.

Navigation Errors



IF YOU DO NOT CALIBRATE CAREFULLY!

IF YOU DO NOT UNDERSTAND RANDOM ERRORS IN ROBOT NAVIGATION

That’s All Folks