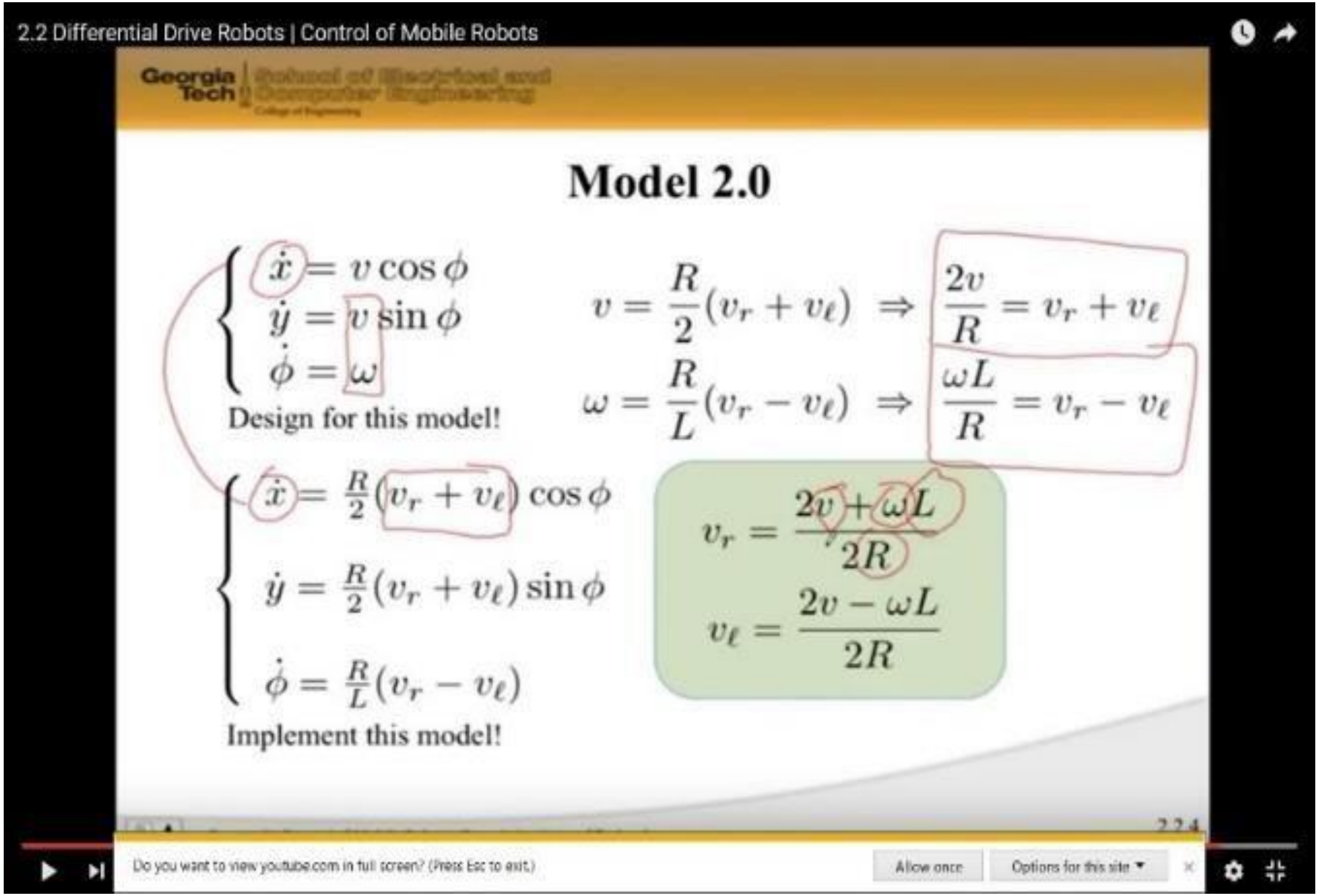
COURSE Review 2
MOBILE ROBOTICS
CENG 5437-01, CENG 4391-02 SPRING 2023

- **Wheeled Robots and Differential Drive Steering Basic Kinematics and Math Basic**
- **Magnus Kinematics of DD Robots**
- **Turtlesim K Control Python program**
- **Calibration - Theory and Practice**

- **Don’t Punch the Robot – Go for the Sensors**
- **SENSORS Classes of Sensors Characterization of Sensors Types of Errors – Statistical and Random**
- **Specific Sensors Position- Absolute and Relative Range**
- **Sensor Accuracy and Precision**

- **Connect Sensors to the Computer – A2D converters, etc.**
- **Sampling Theorem and Aliasing**

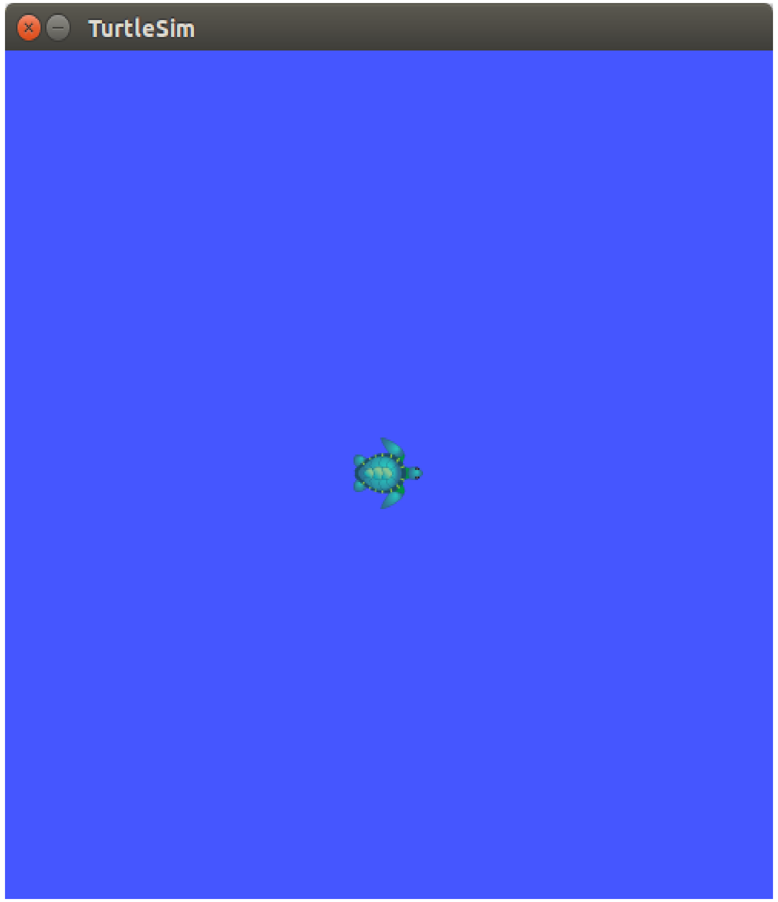
CONTROL – WHEEL VELOCITY, ROTATION

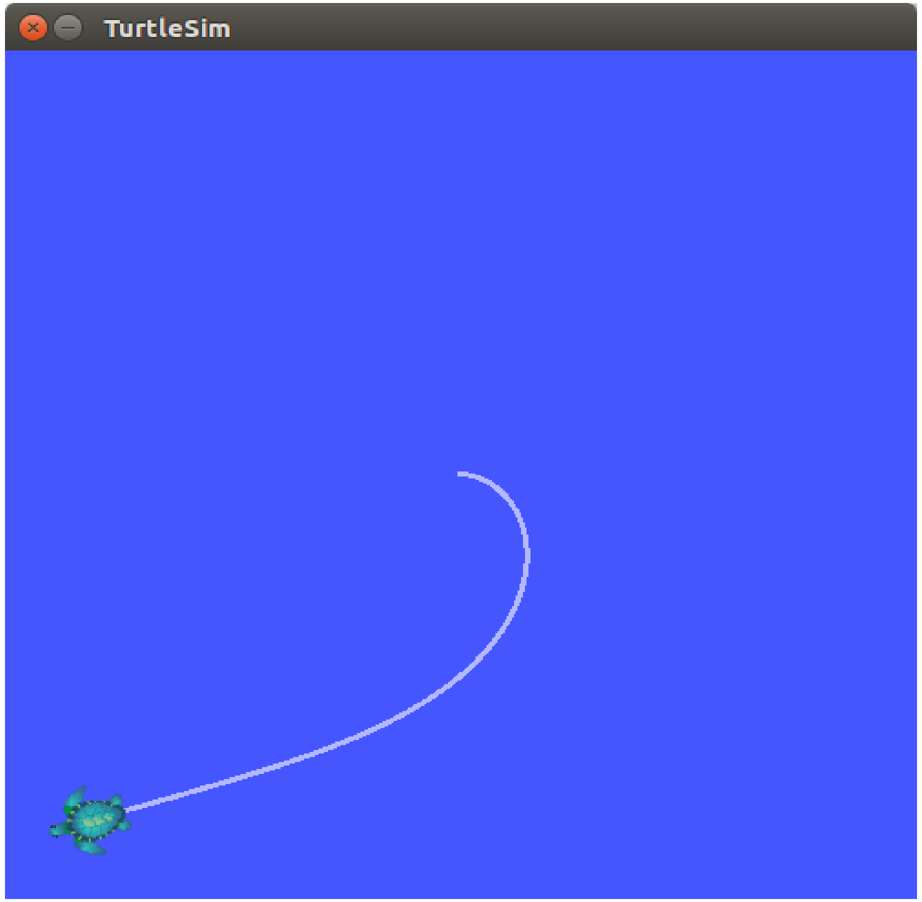


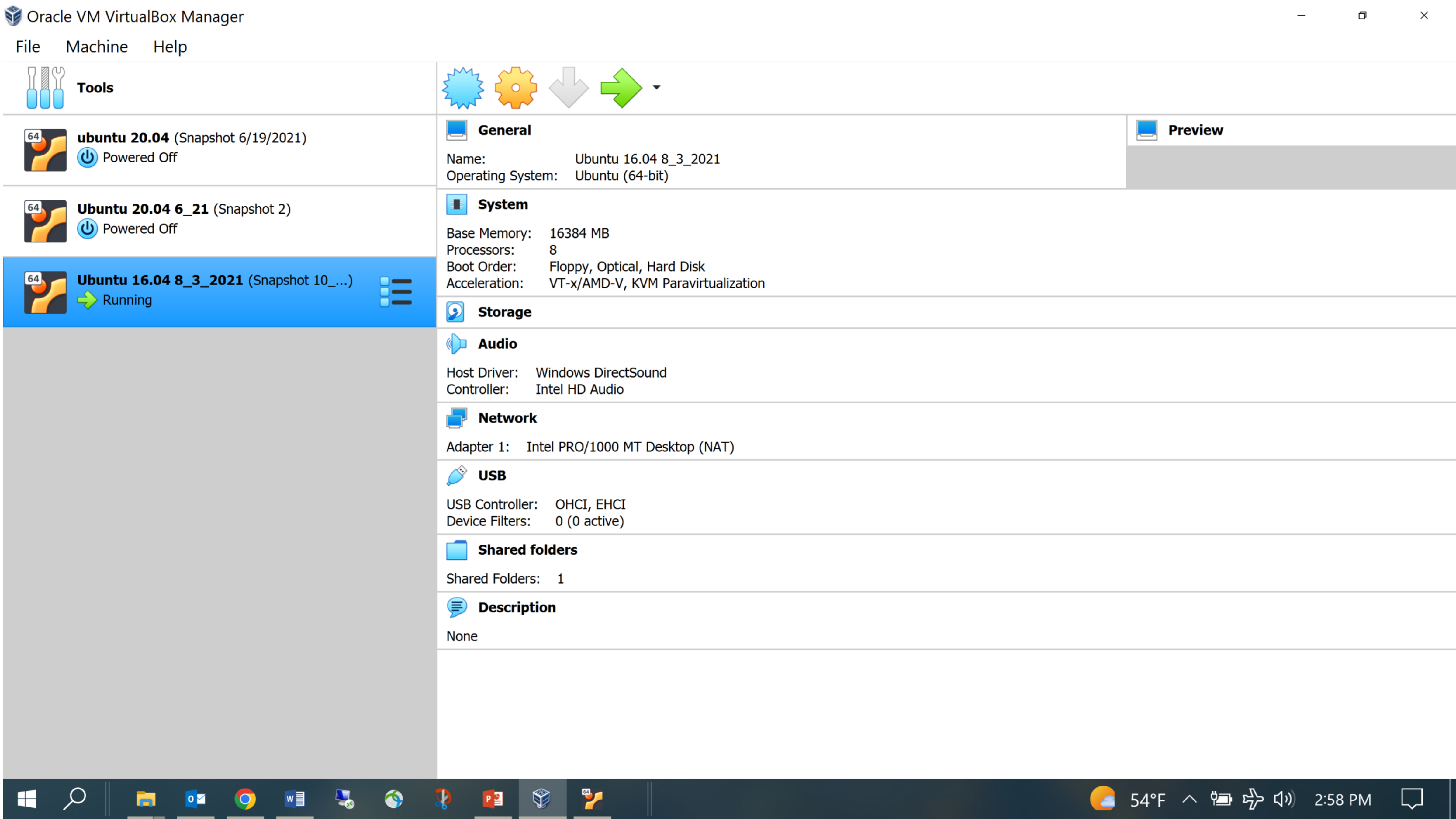
MAGNUS

https://www.youtube.com/watch?app=desktop&v=aE7RQNhwnPQ&sns=em

ROS_PythonKControl_Tsim






Oracle VM VirtualBox Manager
File
Machine
Help
Tools
ubuntu 20.04 (Snapshot 6/19/2021)
Powered Off
Ubuntu 20.04 6_21 (Snapshot 2)
Powered Off
Ubuntu 16.04 8_3_2021 (Snapshot 10_...)
Running
General
Name: Ubuntu 16.04 8_3_2021
Operating System: Ubuntu (64-bit)
Preview
System
Base Memory: 16384 MB
Processors: 8
Boot Order: Floppy, Optical, Hard Disk
Acceleration: VT-x/AMD-V, KVM Paravirtualization
Storage
Audio
Host Driver: Windows DirectSound
Controller: Intel HD Audio
Network
Adapter 1: Intel PRO/1000 MT Desktop (NAT)
USB
USB Controller: OHCI, EHCI
Device Filters: 0 (0 active)
Shared folders
Shared Folders: 1
Description
None
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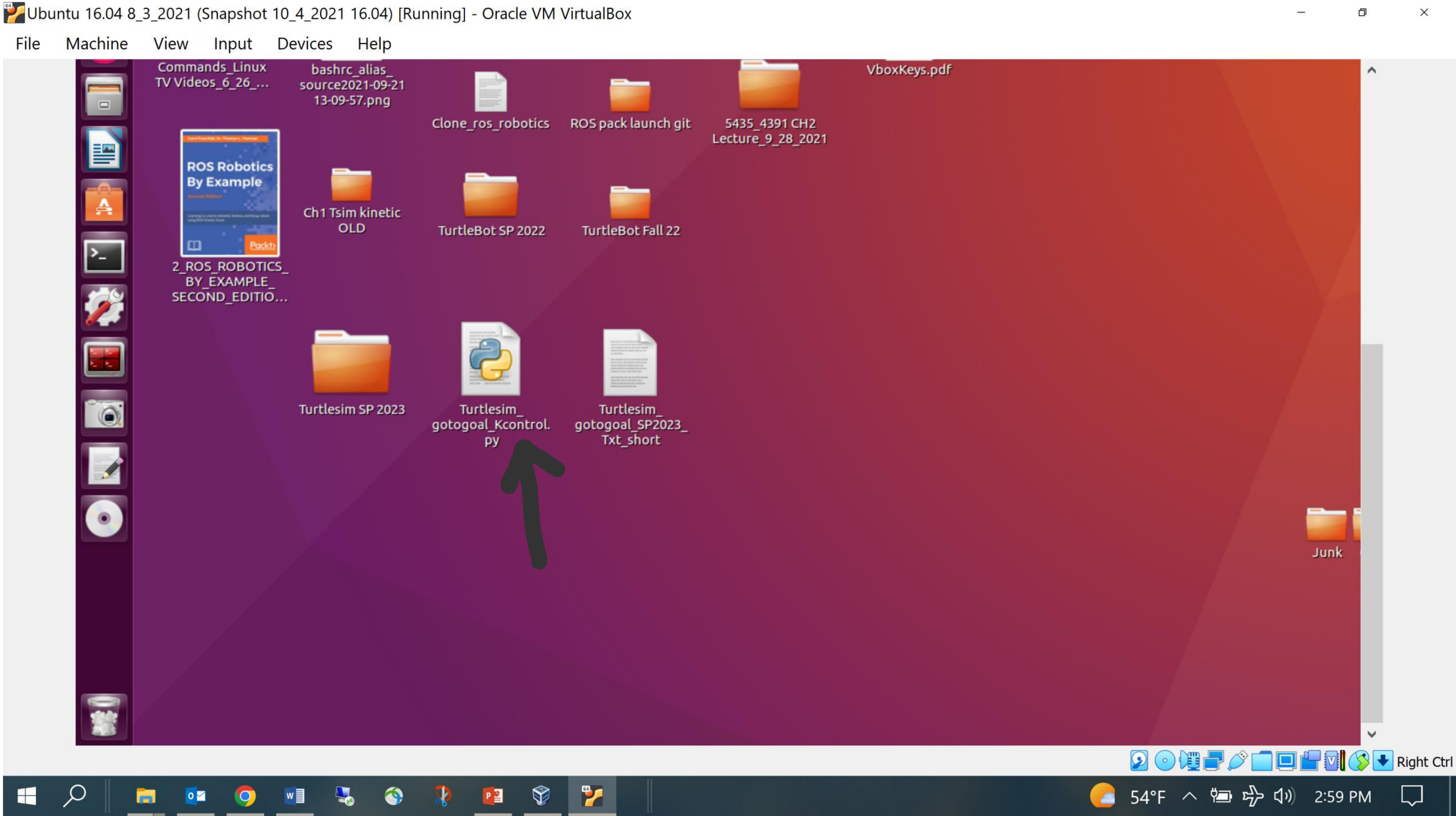
Ubuntu 16.04 8_3_2021 (Snapshot 10_4_2021 16.04) [Running] - Oracle VM VirtualBox
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Machine
View
Input
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Commands_Linux TV Videos_6_26_...
bashrc_alias_ source2021-09-21 13-09-57.png
Clone_ros_robotics
ROS pack launch git
5435_4391 CH2 Lecture_9_28_2021
VboxKeys.pdf
ROS Robotics By Example
2_ROS_ROBOTICS_ BY_EXAMPLE_ SECOND_EDITIO...
Ch1 Tsim kinetic OLD
TurtleBot SP 2022
TurtleBot Fall 22
Turtlesim SP 2023
Turtlesim_ gotogoal_Kcontrol. py
Turtlesim_ gotogoal_SP2023_ Txt_short
Junk
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- **Terminal 1 ROSCORE**
- harman@harman-VirtualBox:~$ roscore
- **Terminal 2 Turtlesim**
- harman@harman-VirtualBox:~$ rosrun turtlesim turtlesim_node
- **Terminal 3 cd Desktop Run python script**

harman@harman-VirtualBox:~$ cd Desktop/
harman@harman-VirtualBox:~/Desktop$ python Turtlesim_gotogoal_Kcontrol.p

Set your x goal:1
Set your y goal:1
Set your tolerance:.01

('velocity =', 3.213376056424147)
('Angular Velocity =', -4.71238898038469)
('The answer is', 4)
('x =', 5.5444)
('y =', 5.5444)

Check the Result
harman@harman-VirtualBox:~/Desktop$ rostopic echo /turtle1/pose -n1
x: 1.00947260857
y: 1.00285518169 **Pretty Close**
theta: -2.84877228737
linear_velocity: 0.0
angular_velocity: 0.0

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)

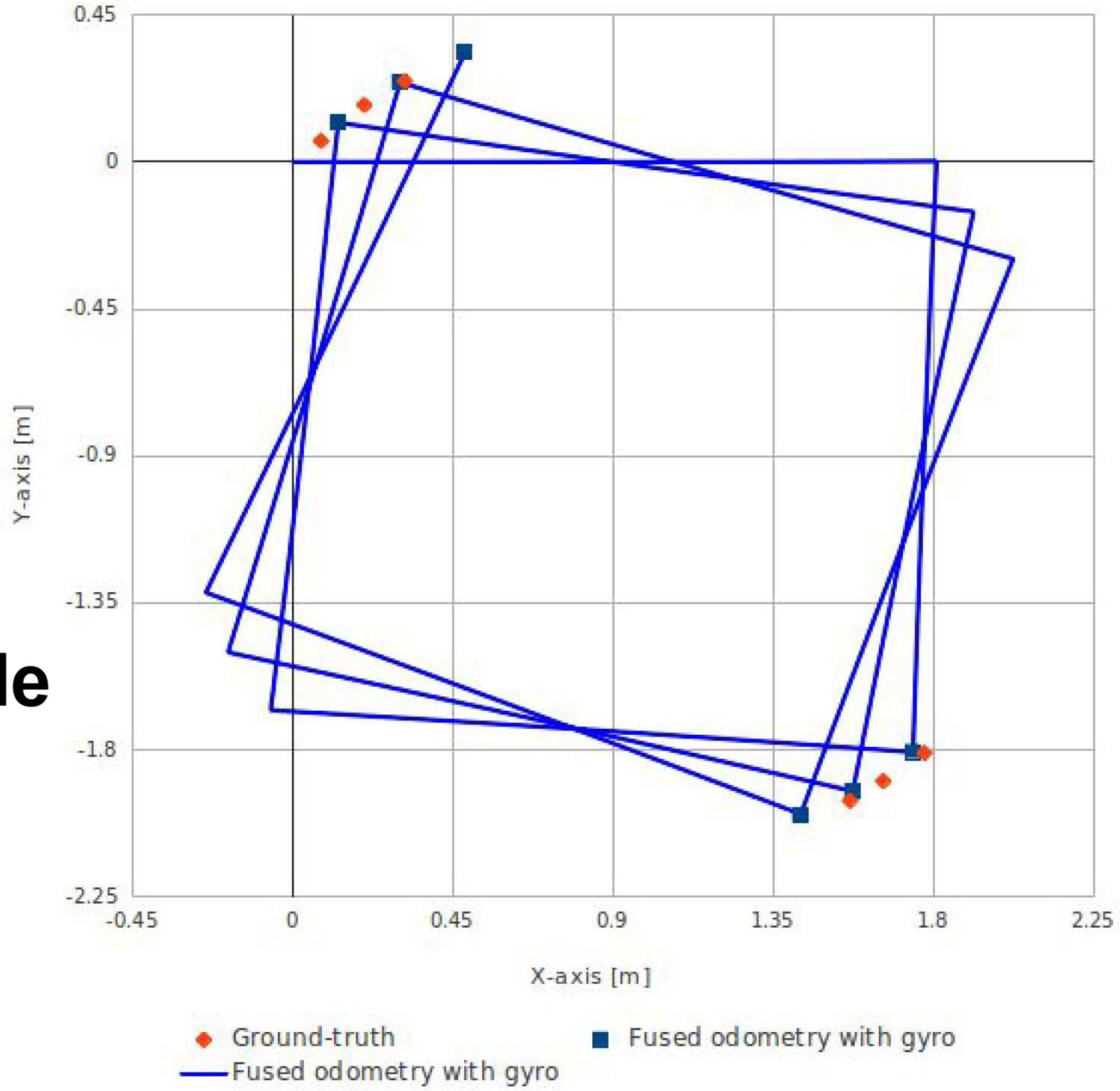
http://www-personal.umich.edu/~johannb/Papers/paper58.pdf

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??

Sensors1_McGill_PDF

March 1

Sensors2_Characteristics_Computer Errors

Sensors3_errors_References

BAD SENSORS – BAD ROBOT!

Sensor_Types GYROS_ROCK!

Sensors_MEMS_Calibration

Sensor_Errors_Examples_Niku_R_AtoD

Niku and TLH Examples

Why Punching a Robot Is a Bad Idea (Go for the Sensors Instead) !

https://www.theatlantic.com/video/index/257060/why-punching-a-robot-is-a-bad-idea-go-for-the-sensors-instead/

CS-417 INTRODUCTION TO ROBOTICS AND INTELLIGENT SYSTEMS

Robot Hardware

Non-visual Sensors

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…

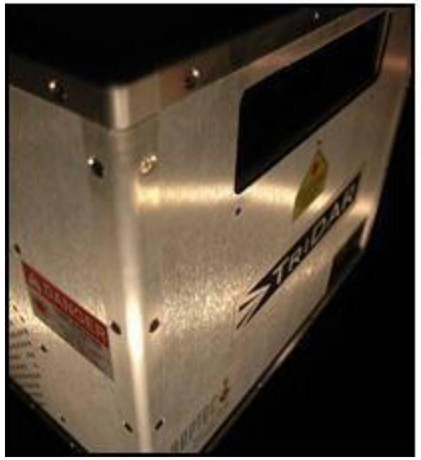
Sensor Characteristics

- **Response Time**: time required for a change in input to cause a change in the output
- **Accuracy**: difference between measured & actual
- **Repeatability**: difference between repeated measures
- **Resolution**: smallest observable increment
- **Bandwidth**: result of high resolution or cycle time

Types of sensor

Specific examples

- tactile
- close-range proximity
- angular position
- infrared
- Sonar
- laser (various types)
- radar
- compasses, gyroscopes
- Force
- GPS
- vision



Infrared Problems

- If the IR signal is detected, it is safe to assume that an object is present
- However, the absence of reflected IR does not mean that no object is present!
  - "Absence of evidence is not evidence of absence."
    C. Sagan
  - certain dark colours (black) are almost invisible to IR
  - IR sensors are not absolutely safe for object detection
- In realistic situations (different colours & types of objects) there is no accurate distance information
  - it is best to avoid objects as soon as possible
- IR are short range
  - typical maximum range is 50 to 100 cm

Sonar Problems

- There are a number of problems and uncertainties associated with readings from sonar sensors
  - it is difficult to be sure in which direction an object is because the 3D sonar beam spreads out as it travels
  - *specular reflections* give rise to erroneous readings
    - the sonar beam hits a smooth surface at a shallow angle and so reflects away from the sensor
    - only when an object further away reflects the beam back does the sensor obtain a reading - *but distance is incorrect*
  - arrays of sonar sensors can experience *crosstalk*
    - one sensor detects the reflected beam of another sensor
  - the speed of sound varies with air temp. and pressure
    - a 16° C temp. change can cause a 30cm error at 10m!

Laser Range Finders

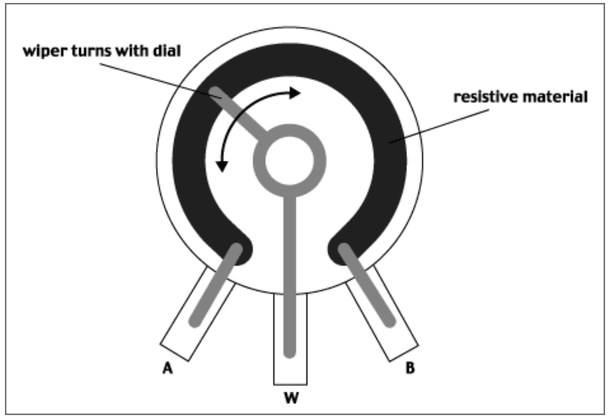
- Laser range finders commonly used to measure the *distance*, *velocity* and *acceleration* of objects
  - also known as *laser radar* or *lidar*
- The operating principle is the same as sonar
  - a short pulse of (laser) light is emitted
  - the time elapsed between emission and detection is used to determine distance (using the speed of light)
- Due to the shorter wavelengths of lasers, the chance of specular reflections is much less
  - accuracies of millimetres (16 - 50mm) over 100m
  - 1D beam is usually swept to give a 2D planar beam
- May not detect transparent surfaces (e.g. glass!) or dark objects

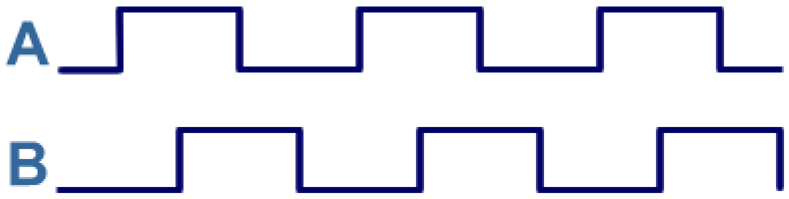
RADAR

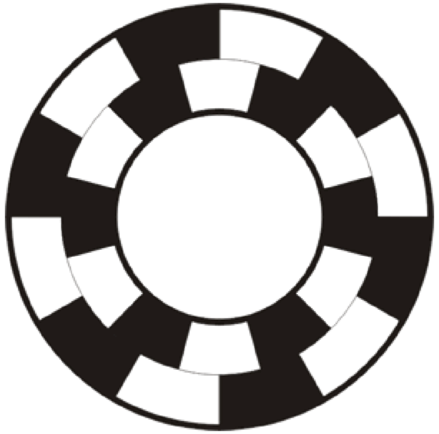
- Radar usually uses electromagnetic energy in the 1 - 12.5 GHz frequency range
  - this corresponds to wavelengths of 30 cm - 2 cm
    - microwave energy
  - unaffected by fog, rain, dust, haze and smoke
- It may use a pulsed time-of-flight methodology of sonar and lidar, but may also use other methods
  - continuous-wave phase detection
  - continuous-wave frequency modulation
- Continuous-wave systems make use of Doppler effect to measure relative velocity of the target

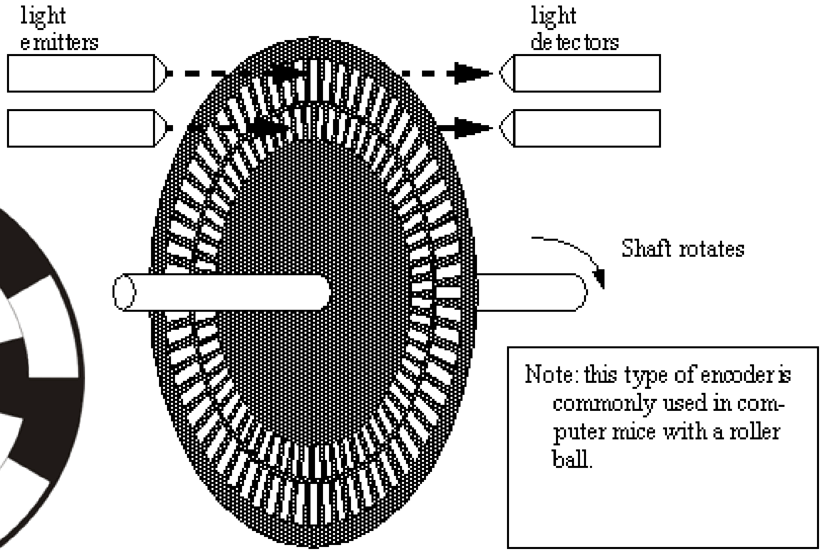
Angular Position: Rotary Encoder

- Potentiometer
  - Used in the Servo on the boebots
- Optical Disks (Relative)
  - Counting the slots
  - Direction by having pars of emitters/receivers out of phase: Quadrature decoding
  - Can spin very fast: 500 kHz









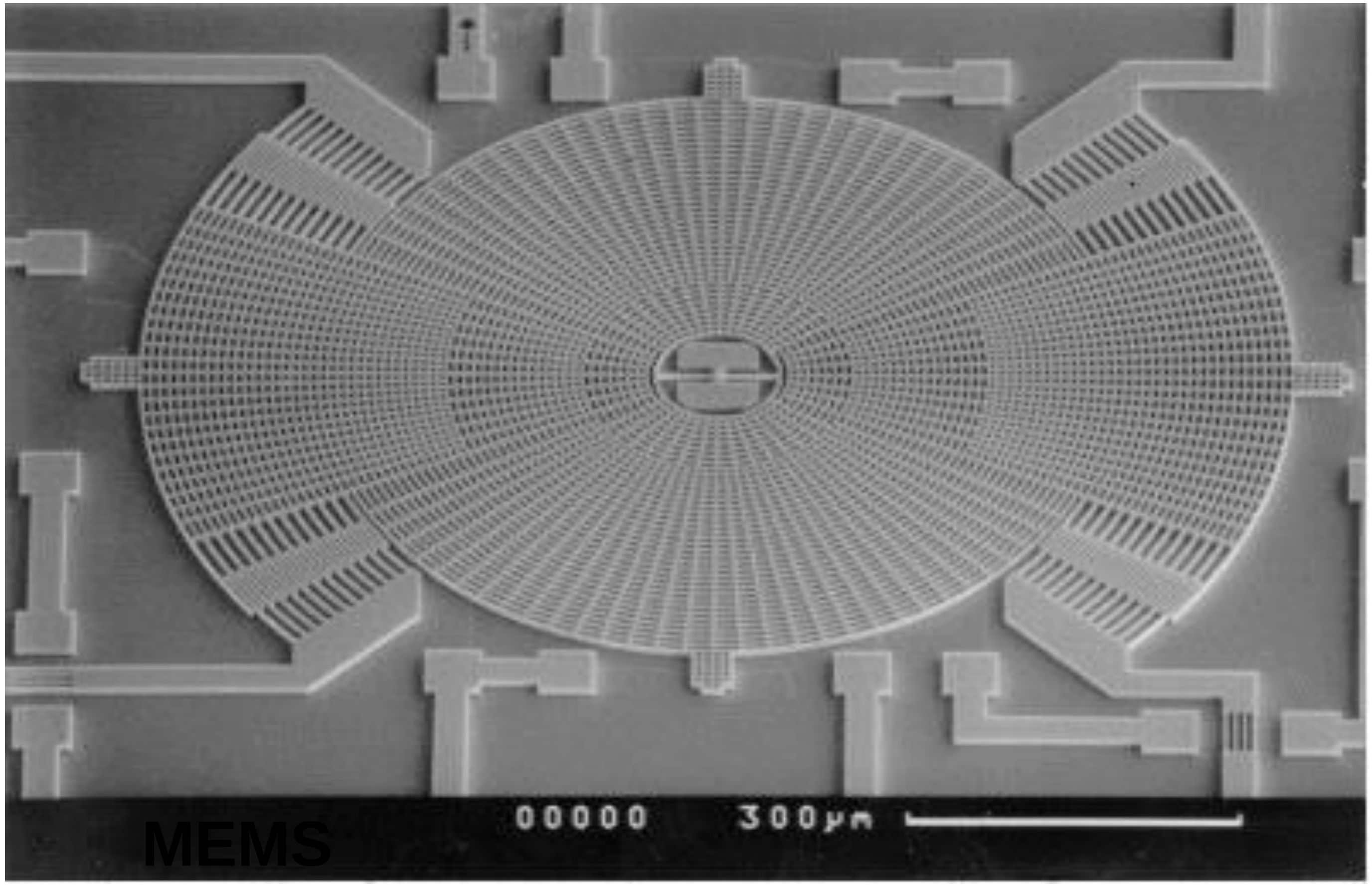
Compass Sensors

- Compass sensors measure the horizontal component of the earth's magnetic field
  - some birds use the vertical component too
- The earth's magnetic field is very **weak** and **non-uniform,** and **changes over time**
  - indoors there are likely to be many other field sources
    - steel girders, reinforced concrete, power lines, motors, etc.
  - an accurate absolute reference is unlikely, but the field is approx. constant, so can be used for local reference

Gyroscopes

- A gyroscope is a spinning wheel with most of its mass concentrated in the outer periphery
  - e.g. a bicycle wheel
- Due to the law of *conservation of momentum*
  - the spinning wheel will stay in its original orientation
  - a force is required to rotate the gyroscope
- A gyro. can thus be used to maintain orientation or to measure the rate and direction of rotation
- In fact there are different types of mechanical gyro.
  - and even optical gyro's with no moving parts!
    - these can be used in e.g. space probes to maintain orientation

Vibrating Structure Gyroscopes

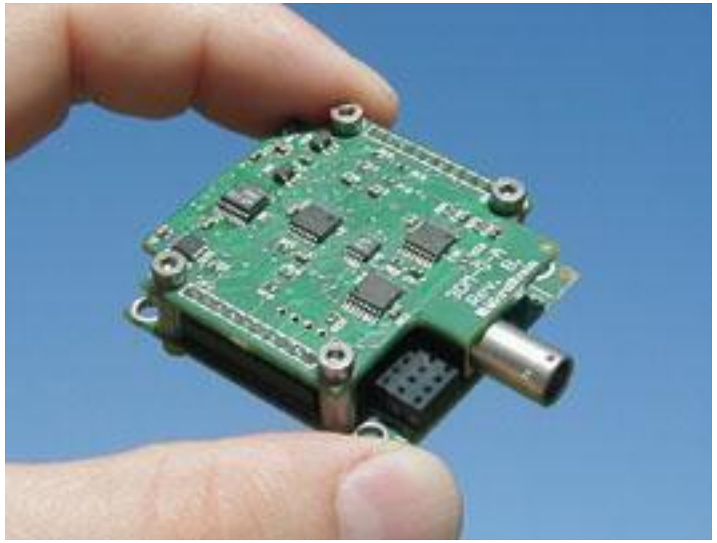


Ring gyro's

- Use standing waves set up
  - between mirrors (laser ring gyro)
  - within a fiber optic cable (fibre optic ring gyro)
- Measure rotation by observing beats in standing wave as the mirrors "rotate through it".

IMU's

- Gyro, accelerometer combination.
- Typical designs (e.g. 3DM-GX1™) use tri-axial gyros to track dynamic orientation and tri-axial DC accelerometers along with the tri-axial magnetometers to track static orientation.
- The embedded microprocessors contains programmable filter algorithms, which blend these static and dynamic responses in real-time.



GPS

- GPS uses a constellation of between 24 and 32 Medium Earth Orbit satellites.
- Satellite broadcast their position + time.
- Use travel time of 4 satellites and trilateration.
- Suffers from “canyon” effect in cities.

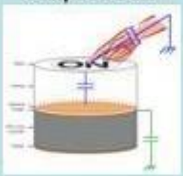
- Error up to 10 meters in some cases. Not Indoors

HW5

Table 2 - Comparison Matrix of Current Sensor Technologies

	Ultrasonic	LIDAR	RADAR	Bi-Static Radar	Vision	AIR Active	PIR Passive
Cost	Low	High	High	Medium	Medium	Low	Low
Computation Overhead	Low	High	Medium	Medium	High	Low	Low
Range	3m	5m to 150m	1m to 150m	5m	Line of sight	2m	20m
Operating Conditions	Clear visibility	Clear visibility to 150m	Normal to heavy rain or snow	Normal to heavy rain or snow	Clear visibility	Normal to slight haze	Clear visibility
Commercially Available	Yes	Yes	Yes	No	Yes	Yes	Yes
Industry Acceptance	High	None	Some	None	None	None	None
Accuracy	±0.05m	±0.3m	±1.0m	±0.1m	NA	NA	NA
Update Frequency	40Hz	400Hz	10Hz	5kHz	<30Hz	NA	NA
Potential for Object Discrimination	Low	Some	Low	Low	High	None	Low
Detection Capabilities	Distance	Distance, speed, geometry	Distance, speed, cross section	Distance and radar cross section	Distance, speed, geometry, object class data	Presence	Presence
Minimum Target Size	Basketball	1" square or larger	Motorcycles and larger	Motorcycles, Pedestrians, and larger	Varies with distance	Pedestrians	Small animals

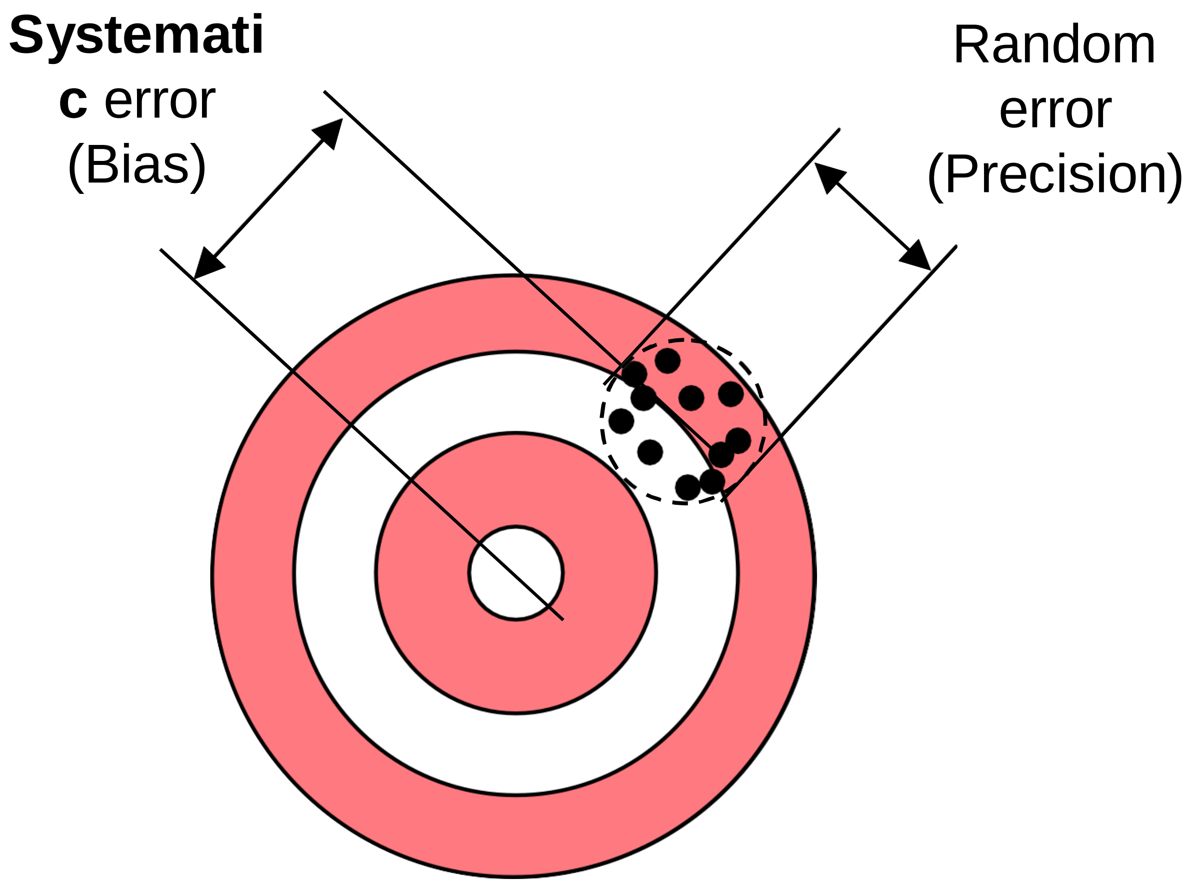
Texas Instruments Sensor Summary Chart

Sensors	Detection range	Detection angle	Range resolution	Detectable information	Bad weather	Night operation	Detection performance
mmWave 	Long	Narrow and wide	Good	Velocity, range, angle	Good	Yes	Robust and stable
Camera 	Medium	Medium	Medium	Target classification	Poor	No	Complexity to calculate object coordinates
LIDAR 	Long	Narrow and wide	Good	Velocity, range, angle	Poor	No	Poor in bad weather
Ultrasonic 	Short	Wide	Good	Range	Poor	No	Short-range applications
CapTIvate 	Short	Narrow	Good	Proximity, pressure	Good	Yes	Very short-range applications

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)

Example: systematic and random errors



• **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.

https://electronics.stackexchange.com/questions/98357/is-the-error-in-a-5-resistor-consistent-across-measurements

> What I'm really saying is that if a given resistor is "off" by 3.5% I don't really care... as long as it's **always** off by the same 3.5%. But if from one measurement (voltage? current?) to another it might be +2% one time and -3% another time, then I need to get higher quality components ?

The answer to your questions is mostly covered in the data sheets. A 5% tolerance resistor will also have a specification for temperature drift, "load life" (drift with time under certain environmental conditions) and so on. It's possible to make a 1% resistor that is just as crappy as a 5% resistor in stability, it's just trimmed closer to begin with (and at a certain temperature). Calibration can reduce the initial inaccuracy, but it won't reduce the other kinds of drift. The drift will determine whether you can make a 0.1% circuit with 1% resistors or a 0.5% circuit with 5% resistors.

Temperature Coefficient	1 Ω ≤ R ≤ 10 Ω	±200 ppm/°C
	10 Ω < R ≤ 10 MΩ	±100 ppm/°C
	10 MΩ < R ≤ 22 MΩ	±200 ppm/°C

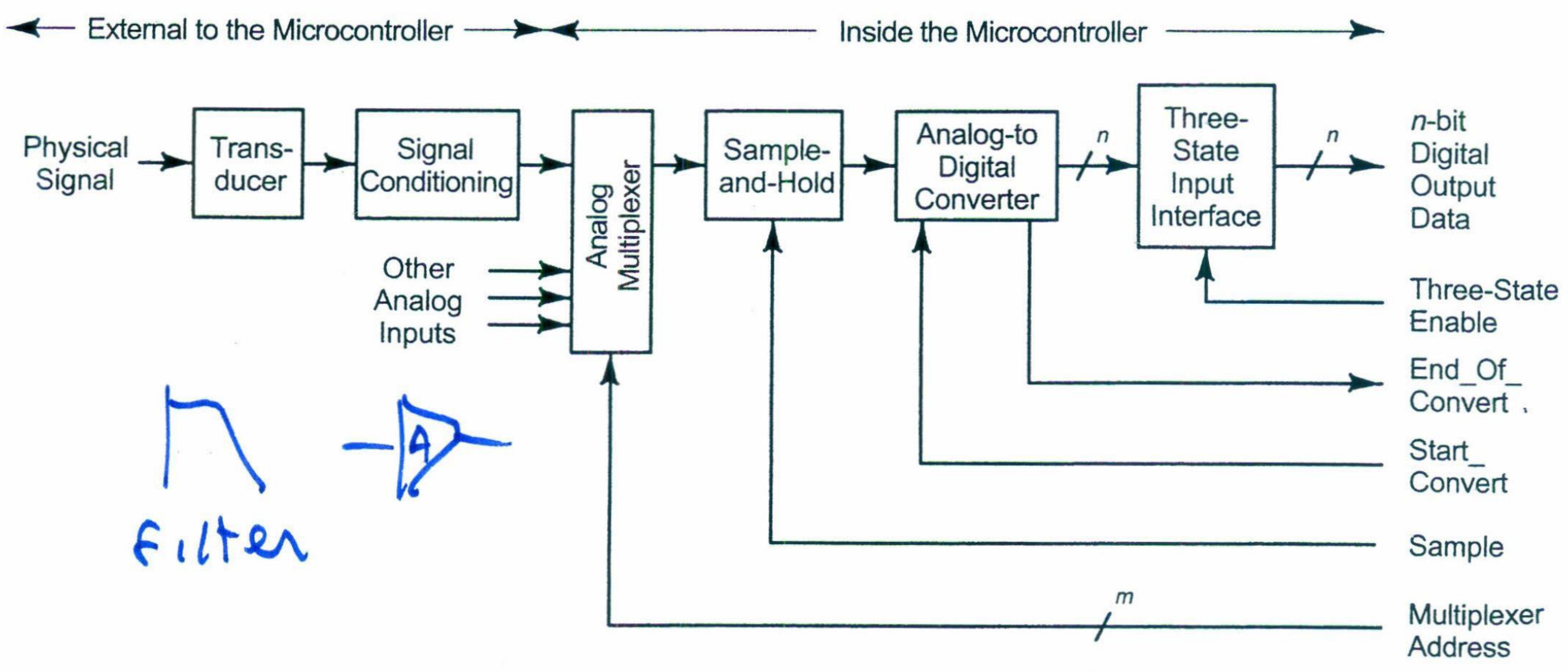


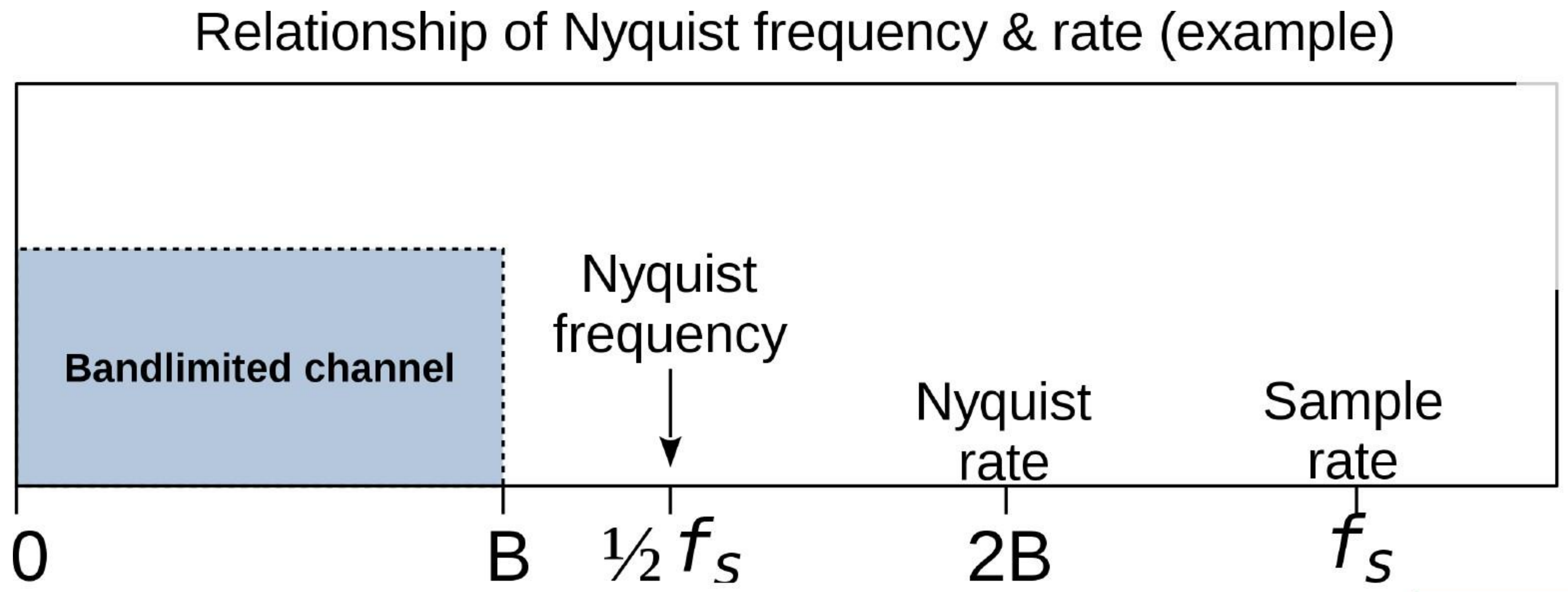
Figure 13-1 Data acquisition system.

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 $2f_{\max}$.



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

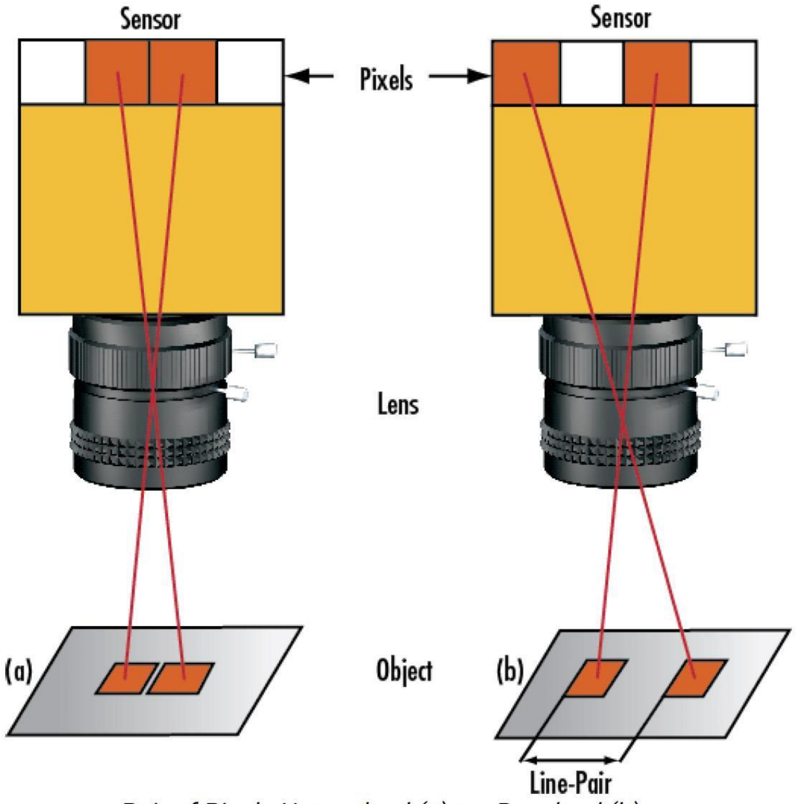


Figure 2: *Pair of Pixels Unresolved (a) vs. Resolved (b)*

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.

IF YOU DO NOT CALIBRATE CAREFULLY!

IF YOU DO NOT UNDERSTAND RANDOM ERRORS IN ROBOT NAVIGATION