INTRODUCTION TO ROBOTICS, PATH TRACKING, ROBOT ANATOMY

Ola Ringdahl

UMEÅ UNIVERSITY

ROBOTICS LECTURES IN THIS COURSE

L1
- Introduction to robotics
- Path tracking
- Robot anatomy

L2
- Potential fields
- Robot paradigms

L3
- ~~Biological inspiration~~

CONTENTS OF THIS LECTURE

1. Introduction to robotics
2. Path tracking
3. Robot anatomy (part 1)

INTRODUCTION TO ROBOTICS

Readings:
Dudek - Overview (p1-11).pdf

CONTENTS OF PART 1

- What are we talking about?
- Different kinds of robots
- Why do we need them at all?
- The prehistory of Robotics
- Challenges

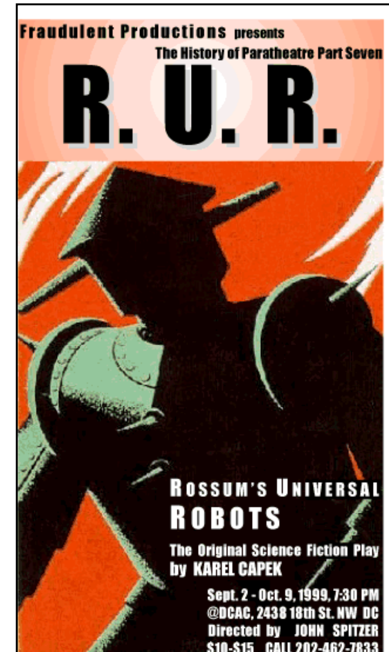
THE WORD "ROBOT"

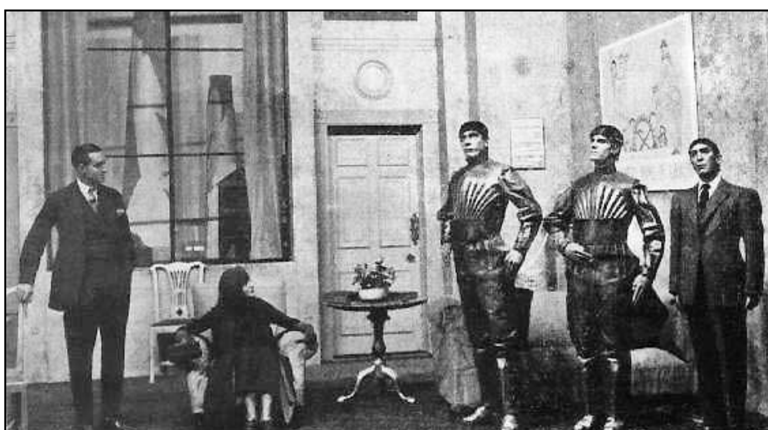
It was first used in 1920 in a play called "R.U.R." or "Rossum's Universal Robots" by the Czech writer Karel Capek.

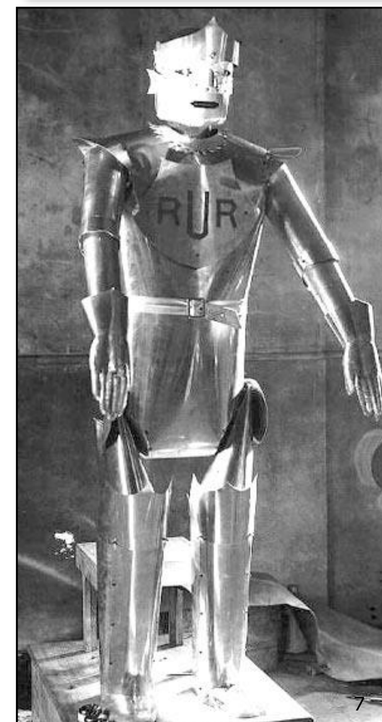
The story: Man makes robot - then robot kills man!

Many movies continued on this theme.

"Robot" also sometimes applies to programs that search the web (bots, spiders)







CURRENT STATE OF ROBOTICS

- Robots of today are not the walking talking intelligent machines of movies and books.

- Until ~2014, most robots worked in factories, warehouses, and laboratories.

- Since then, most robots are service robots: lawnmowers and vacuum cleaners.

- Now robots are starting to show up in our schools, stores, offices, and even in our bodies.

DEFINITIONS OF "ROBOT"

- Robot Industry Association (RIA):

"A re-programmable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmable motions for the performance of a variety of tasks".

- An "AI definition":
  A machine able to extract information from its environment and use knowledge about its world to move safely in a *meaningful* and *purposive* manner.

TWO MAJOR TYPES OF ROBOTS

Industrial robots

- Operate in a stable deterministic environment
- Normally fixed or restricted mobility
- Operate with no or limited interaction with the world
  - Although collaborative robots becomes more common

Service robots

- Operate in "the real world"
- Move around
- Require a high degree of autonomy
- Interact with the environment

PROFESSIONAL SERVICE ROBOTS

- **harvesting robots**
- **transportation robots**
  - agriculture, forestry, mining, …
- **inspection and maintenance**
  - pipelines, sewers, pool cleaning
- **medical robots**
  - remote surgeon
- **defense**
  - surveillance, patrolling, shooting, bomb/mine disposal
- **rescue and security robots**
  - USAR, patrolling
- **construction and demolition robots**
- **space robots**
  - exploration, assembly & assistance

PERSONAL SERVICE ROBOTS

- customer relations
- home security
- handicap/elderly assistance
- education
- domestic

UMEÅ UNIVERSITY

WHY ROBOTS?

The ~~3~~ 5 D’s:

- Dirty
- Dull
- Dangerous
- Difficult
- Distant

$ Dollar

UMEÅ UNIVERSITY

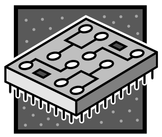
WHY ROBOTS?
(SPECIFICALLY FOR INDUSTRIAL ROBOTS)

To

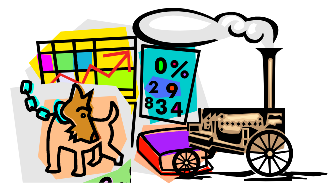
- Improve productivity
- Increase production
- Improve working conditions
- Improve quality
- Improve flexibility
- Lack of workers

THE PREHISTORY OF ROBOTICS

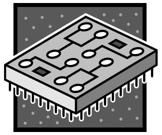
- Control



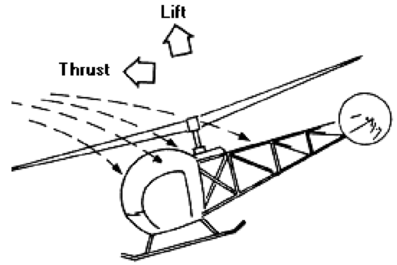
- Cybernetics

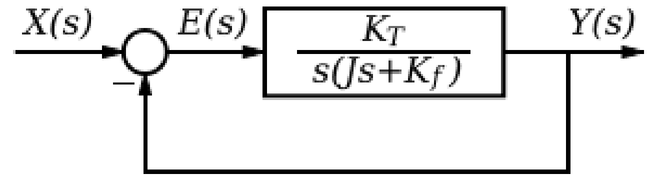


- Artificial intelligence



The prehistory of Robotics… Control



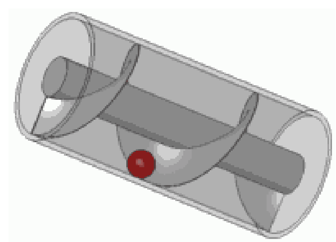


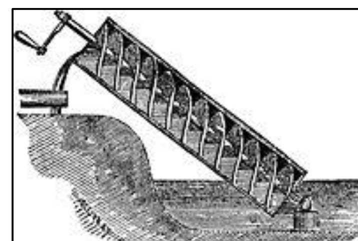
What is Control?

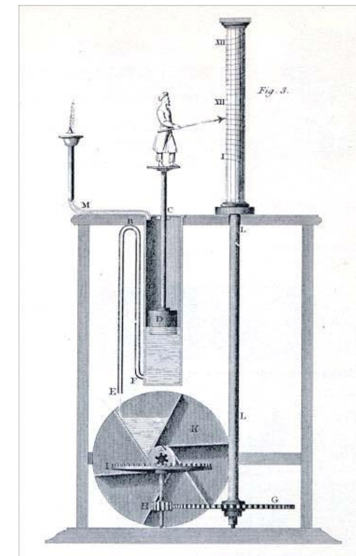
Fundamental concepts governing all mechanical systems (steam engines, airplanes, cranes, etc.)

Thought to have originated with the ancient Greeks:

- Clocks
- Water pumps

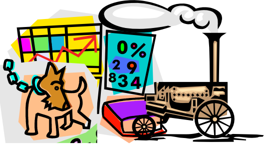






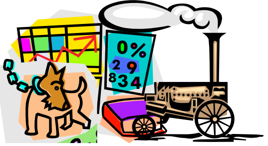
Forgotten and rediscovered in Renaissance Europe:

- Heat-regulated furnaces
- Windmills
- James Watt's steam engine (the governor)



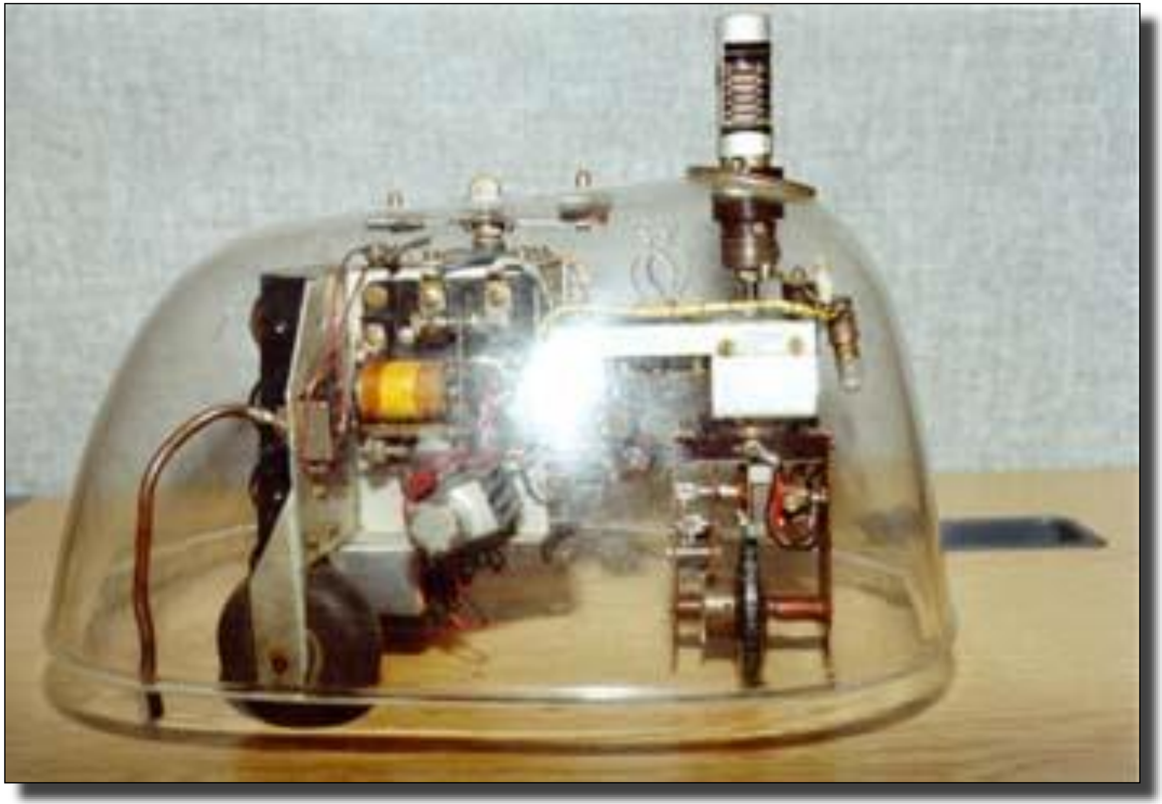
THE PREHISTORY OF ROBOTICS… CYBERNETICS

- A combination of biology, information science, control theory
- Developed by Norbert Wiener in the late 1940
- Seeks to explain the common principles behind control and communication in animals and machines
- Studied the coupling between an organism and its environment



1953: GRAY WALTER’S TORTOISE

- Seeking light
- Head toward weak light
- Back away from bright light
- Turn and push
  (for obstacle avoidance)
- Recharge battery



THE PREHISTORY OF ROBOTICS … AI

AI was born at the Dartmouth Research Conference in August 1955

Marvin Minsky 1955:

“[an intelligent machine] would tend to build up within itself an abstract model of the environment in which it is placed. If it were given a problem it could first explore solutions within the internal abstract model of the environment and then attempt external experiments”.

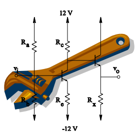
This view dominated AI and robot research for 30 years.

Shakey (1966-72)

ROBOTICS: MULTIDISCIPLINARY

Classical AI

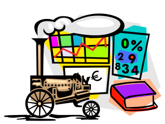
- Knowledge representation, Natural language processing,
- Planning, Searching
- Perception



Mechatronics

- Sensors, Actuators

Control theory



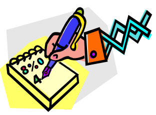
- To control motion and manipulation

ROBOTICS: MULTIDISCIPLINARY

Signal processing

- Image processing, Prediction, Filtering

Machine learning

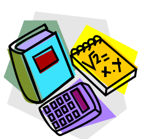


- Pattern recognition, Neural networks, Fuzzy logic, Genetic algorithms

Computer Science

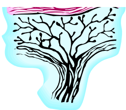
- Software engineering, Architectures

Numerical methods



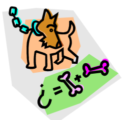
- Control, Optimization, Parameter estimation in models

ROBOTICS: MULTIDISCIPLINARY



Neurophysiology

- Human control systems

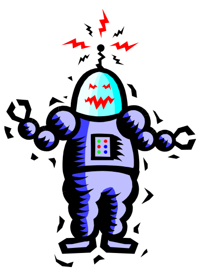


Ethology

- Animal behavior

Psychology

- Human behavior



Robotics

- Navigation (Localization, Path planning, Map making, Obstacle avoidance),
- Human-Robot Interaction (HRI), Robot ethics

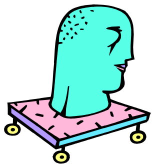
CHALLENGES

Perception

- Unstructured environments (Object recognition and Speech recognition)

Control

- Manipulation of objects in the real world
- Limited capabilities of robot actuators/effectors
- Power consumption



Thinking

- Situational awareness, Problem solving, Knowledge representation, Natural language processing (NLP), Learning

System level

- Robot safety
- Human-robot interaction (HRI)
- Networks of robots

UMEÅ UNIVERSITY

PATH TRACKING FOR MOBILE ROBOTS

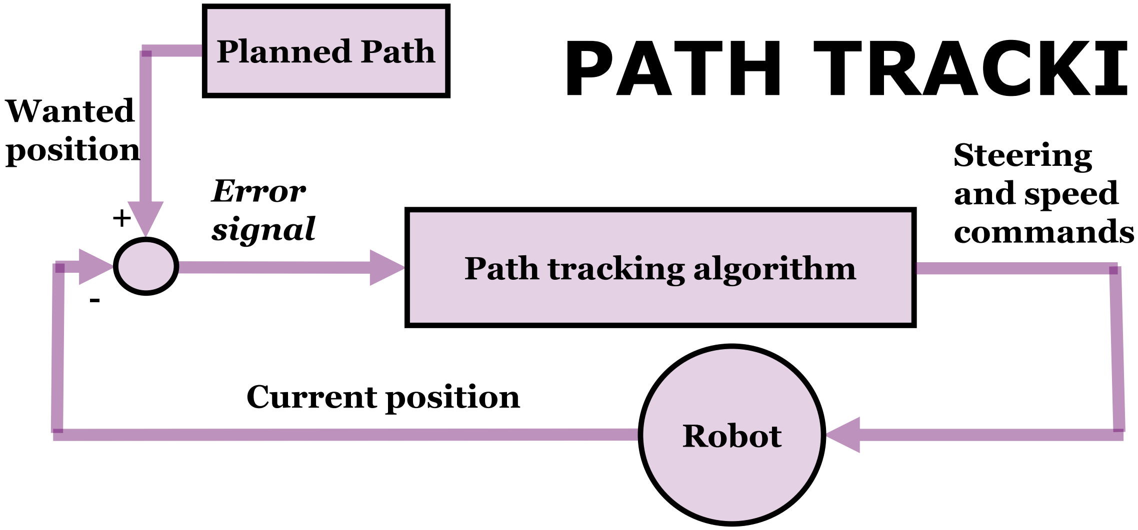
Readings:

Coulter 1992 Pure Pursuit.pdf

Ringdahl 2003 Master thesis.pdf (Ch. 3)

ROBOT NAVIGATION

- We want to control where the robot goes!
- Often we know where the robot is, and where it should go (but not how)
- Path planning creates a path
  - More in the next AI course
  - and with Potential fields later on in this course
- Sometimes a path is given
  - like in the assignment



PATH TRACKING

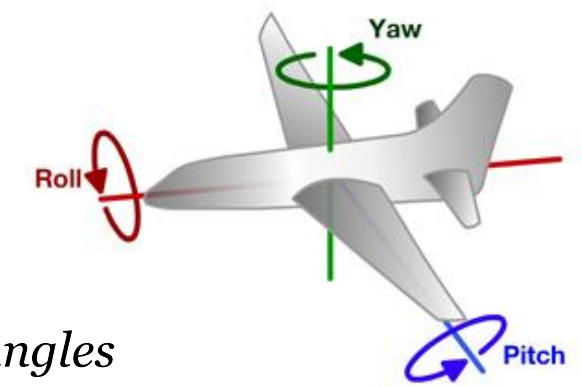
- The control algorithm that makes the robot follow a given path
- Intuitively: If to the left of the path: turn right. If to the right of the path: turn left. But don't turn too little, and not too much!
- In general: A non linear control problem
- Two intuitive algorithms:
    - Follow-the-carrot
    - Pure pursuit

THE ROBOT POSE

- Describes a robot's location in 3D space
- A mobile robot has 6 degrees of freedom (DOF) expressed by the pose: $(x, y, z, \phi , \theta, \psi)$
- Position = (x,y,z)
- Attitude = (roll, pitch, yaw)

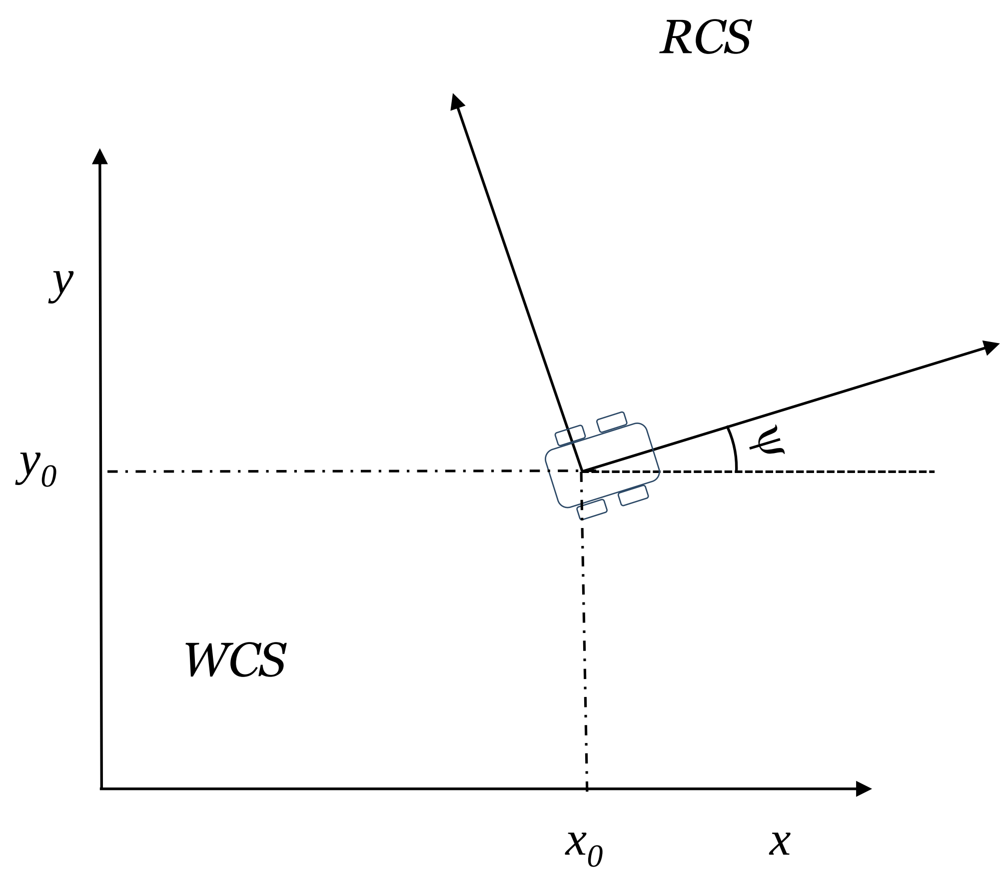
  = (ϕ, θ, ψ)

  = (phi, theta, psi)
- roll, pitch, and yaw are denoted *Euler angles*



TWO 2D COORDINATE SYSTEMS

- The robot has its own coordinate system (RCS)
- So does the world (WCS)
- The robot's pose describes the relation between RCS and WCS
- For indoors robots, we often make the *"flat ground assumption"*: The robot moves in a flat 2D world. The pose is then simply (x, y, ψ) where ψ is the yaw (a.k.a. heading)



CONVERSION BETWEEN COORDINATE SYSTEMS

- Let $(x_o, y_o, \psi)_{WCS}$ denote the robot's pose
- Let P = $(x', y')_{RCS} = (x^w, y^w)_{WCS}$
- Then:

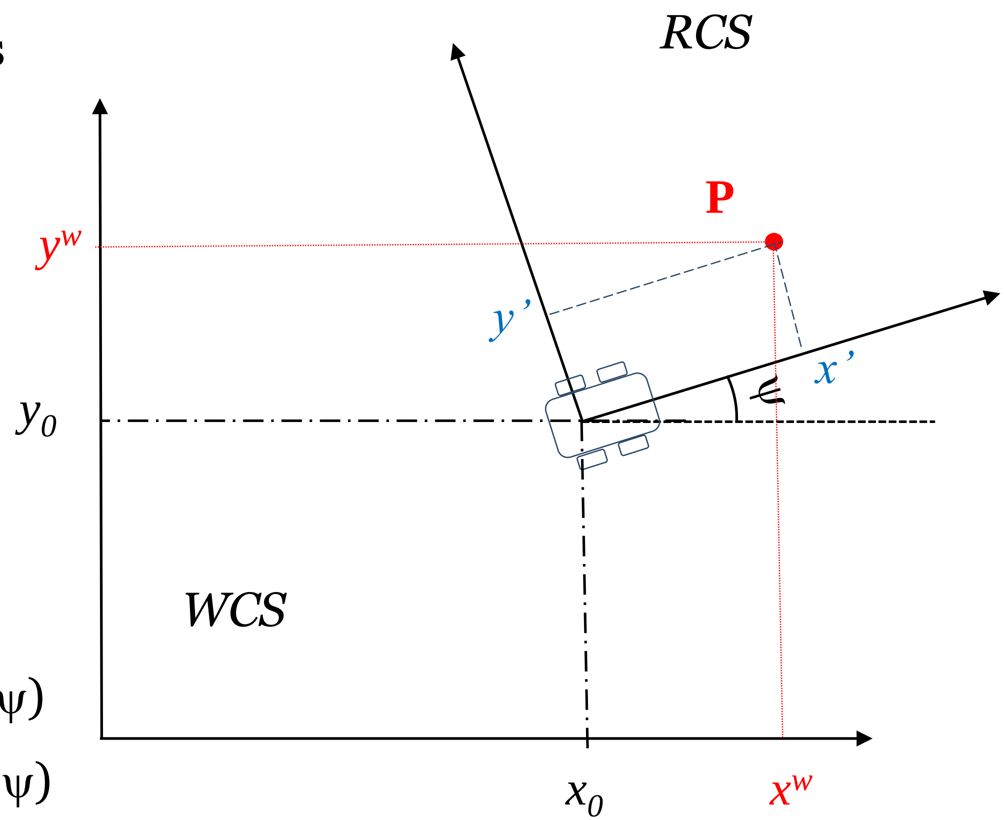
$$x^w = x_o + x' \cos(\psi) - y' \sin(\psi)$$

$$y^w = y_o + x' \sin(\psi) + y' \cos(\psi)$$

- And the other way around:

$$x' = (x^w - x_o) \cos(\psi) + (y^w - y_o) \sin(\psi)$$

$$y' = -(x^w - x_o) \sin(\psi) + (y^w - y_o) \cos(\psi)$$



EULER ANGLES & QUATERNIONS

- *Euler angles* is a way of specifying the angular relation between two coordinate systems
- A problem with Euler angles: one or several angels may not be uniquely defined (denoted *gimbal lock*)
  - Example: What is the yaw of a vehicle moving straight up (pitch=90 degrees)?
  - For this reason, the space industry adopted a different definition of the angles
- *Quaternions* is another representation, and are
  - not susceptible to gimbal lock
  - more compact, quicker to compute and more numerically stable

EULER ANGLES & QUATERNIONS

- According to Euler's rotation theorem, any sequence of rotations around several axes is equivalent to a single rotation by a given angle about a fixed axis
- A quaternion represents this axis and the amount of rotation with four numbers, usually denoted (w,x,y,z)
- The MRDS simulator provides quaternions representing the robot's attitude (corresponding to roll, pitch and yaw in Euler)
- You can convert quaternions to Euler angles by calling a subroutine
    - Don't try to make sense of the quaternion, just convert it!

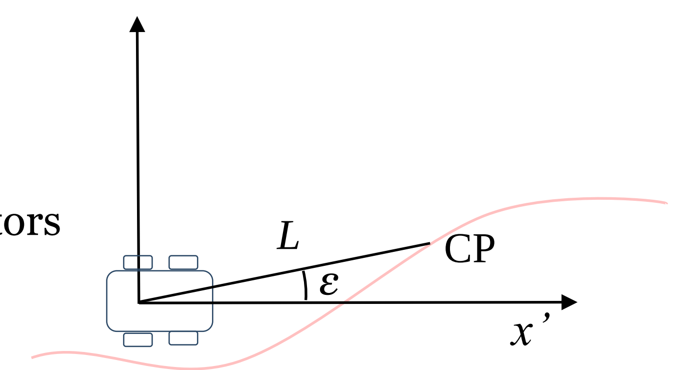
FOLLOW-THE-CARROT

- A simple and common algorithm for path tracking
- Analogy: a driver sitting in a cart pulled by a donkey steers by dangling a carrot in the desired direction in front of the donkey using a fishing-rod
- Algorithm: At each time step, the robot steers towards a point further along the route, with no concern about the appearance of the route before that point.

Barton, M.J., Controller Development and implementation for Path Planning and Following in an Autonomous Urban Vehicle. University of Sydney, November, 2001.

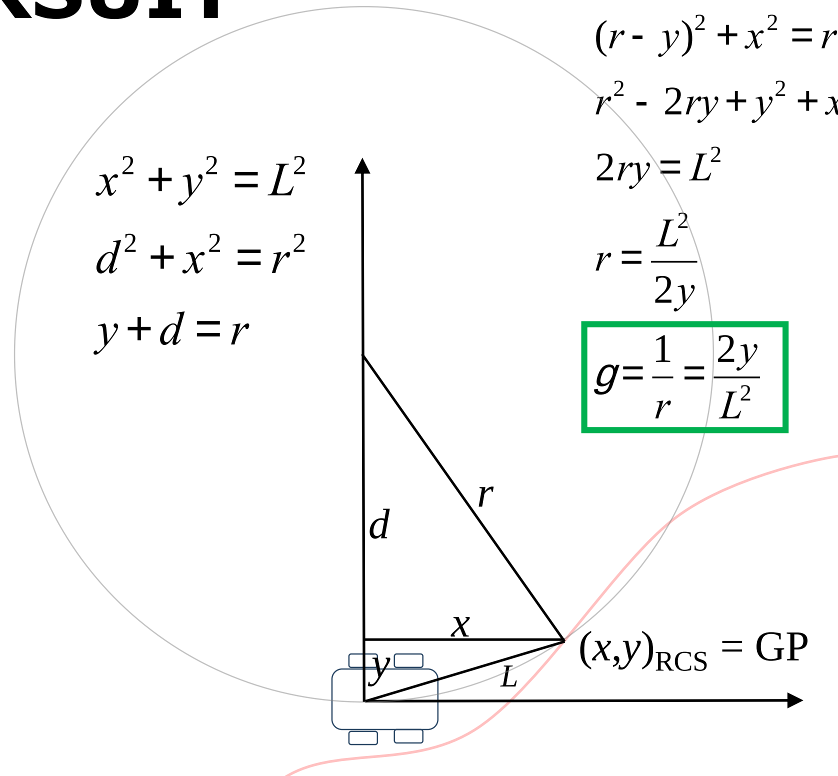
FOLLOW-THE-CARROT

- The carrot point (CP) is defined as the point on the path that is one look ahead distance L away from the robot.
- The orientation error ε is defined as the angle between the x' axis (pointing forward) and the line from the robot to the carrot point
- If $\varepsilon = 0$: the robot points towards CP, i.e. the robot should continue straight ahead
- Otherwise, the steering angle φ or angular velocity ω may be controlled to reduce ε:
  - $\varphi = g1\ \varepsilon$
  - $\omega = g2\ \varepsilon$
  - where g1 and g2 are constant gain factors



PURE PURSUIT

- Uses the fact that the robot moves along circles
- Define a goal point (GP) on the path, at distance L from the robot
- Construct a circle passing through $(0,0)_{RCS}$ and GP, such that the vehicle orientation is a tangent to the circle
- The circle is defined by its radius r and midpoint
- Set φ or ω (turing rate) to correspond to motion along this circle:
  - φ (depends on the mechanical design)
  - $\boxed{\omega = \upsilon\,\Upsilon,}$
  - where υ is the linear speed and $\Upsilon = 1/r$ is the curvature of the circle



$$x^2 + y^2 = L^2$$
$$d^2 + x^2 = r^2$$
$$y + d = r$$

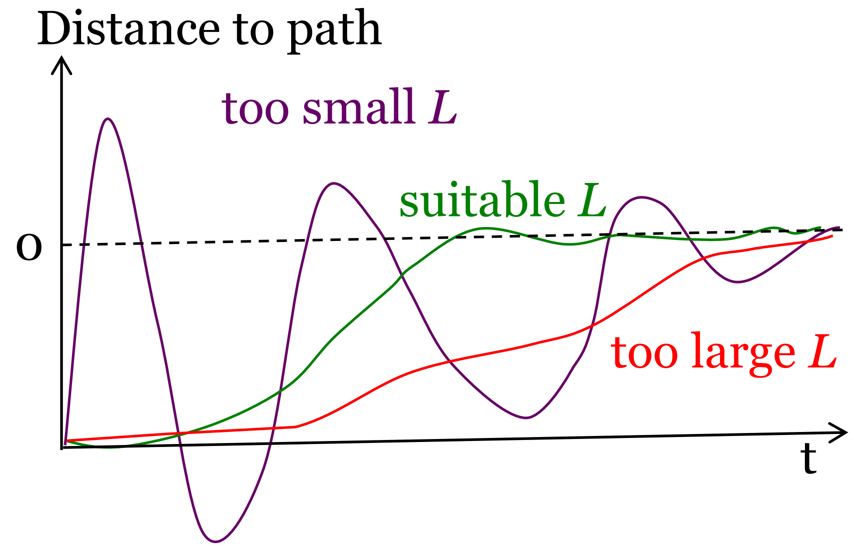
$$d = r - y$$
$$(r - y)^2 + x^2 = r^2$$
$$r^2 - 2ry + y^2 + x^2 = r^2$$
$$2ry = L^2$$
$$r = \frac{L^2}{2y}$$
$$\boxed{g = \frac{1}{r} = \frac{2y}{L^2}}$$

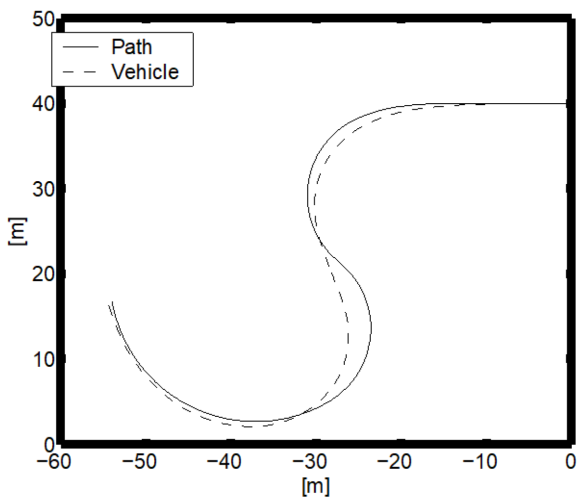
Derivation:
ω=2π/T=2πr/Tr=C/Tr=v/r=vϒ
where *C* is the circumference and *T* is the time it takes to move a full turn around the circle

Reference: *Implementation of the Pure Pursuit Path Tracking Algorithm,* R. Craig Coutier, 1992 (note: different orientation of the robot...)

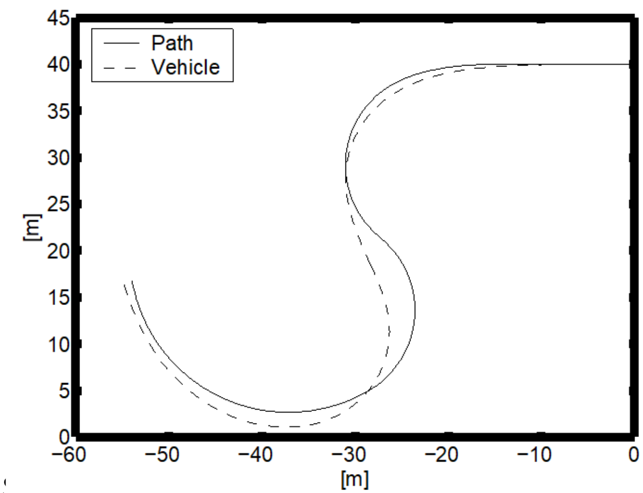
PERFORMANCE

- Pure pursuit is regarded to be better (e.g. works better when the robot is far off the path)
- Quite similar performance in practice
- Both methods oscillate or are slow to reach the path, depending on L
- L may be modified as a function of speed (Urmson et al. 2004)
- General problem: Cutting corners:





Pure pursuit

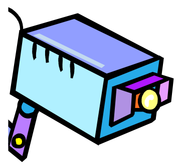


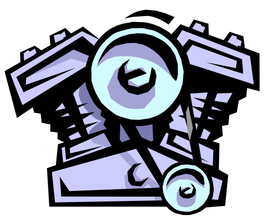
Follow-the-carrot

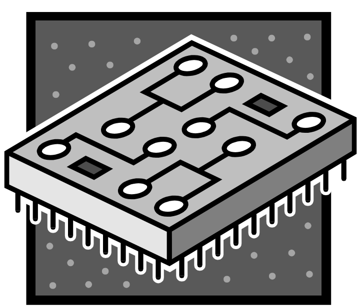
ROBOT ANATOMY (PART 1)

“Anatomy is the study of the structure of the body and its parts”

WHAT CONSTITUTES A ROBOT?





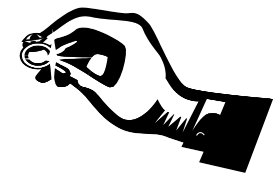


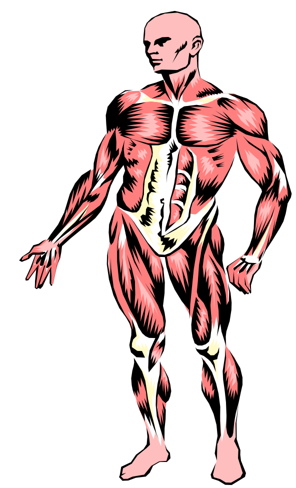
Hardware:

- Sensors
- Effectors/Actuators
- Control unit

Software:

- System software
- Application software





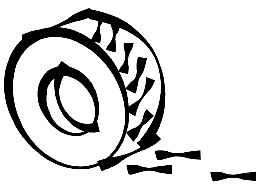
SENSORS

are used by the robot to gain information about the environment (and itself) to guide control

Some typical usages:

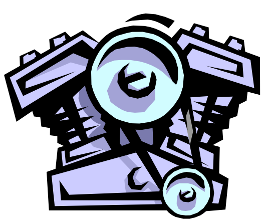
- Avoid collision (distance sensors, “bumpers”)
- Identifying objects (cameras)
- Localization (GPS, odometry)
- Building maps (distance sensors)
- Feedback control (joint sensors)
- …

EFFECTORS & ACTUATORS



Effector

- A device by which a robot has an impact on the environment. Most common two types: *locomotion* and *manipulation*.
- Human effectors: Arms, hands, legs
- Robot effectors: wheels, tracks, grippers, …



Actuator

- A mechanism that enables the effector to execute an action.
- Human actuators: Muscles
- Robot actuators: Electric motors, hydraulic/pneumatic cylinders, solenoids

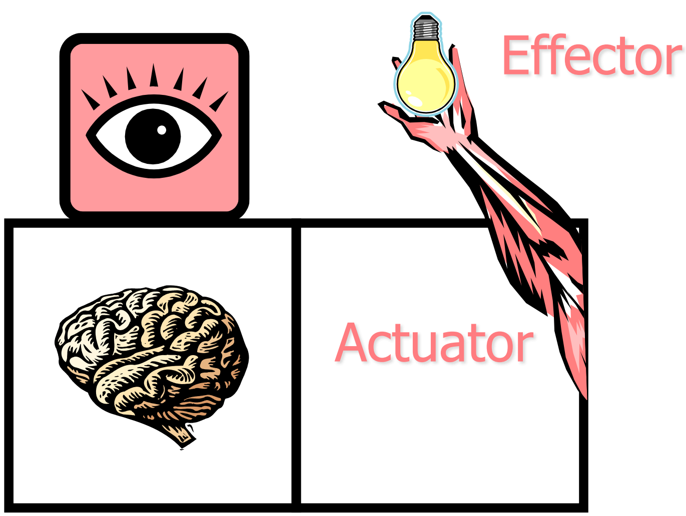
CONTROL UNIT

- Uses sensor data to compute control signals to the actuators that move the effectors
- The computation depends on the task:
  - Move a robot arm in a fixed pattern (e.g. spray painting)
  - Look for humans (shop assistant robots)
  - Find the shortest way out of the building (rescue robots)
  - Do the laundry!
  - ...
- Human control units: A brain
- Robot control units: Most often a computer

Putting it all together:
Two implementations

A human being

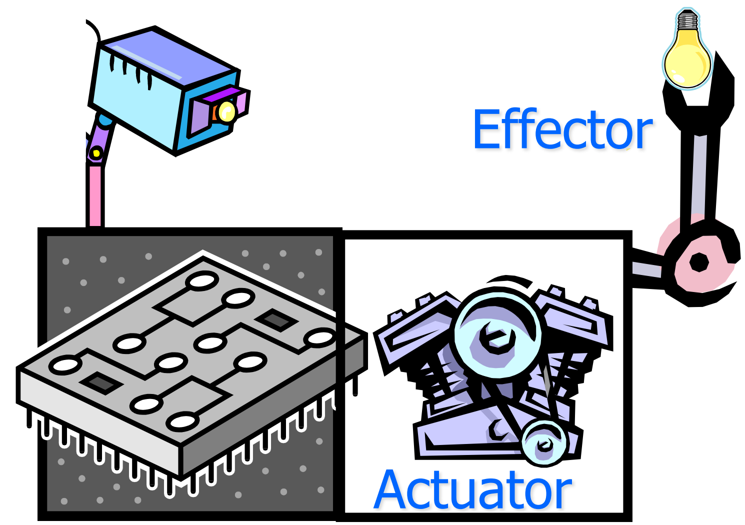
Sensor



Control unit

A robot

Sensor



Control unit

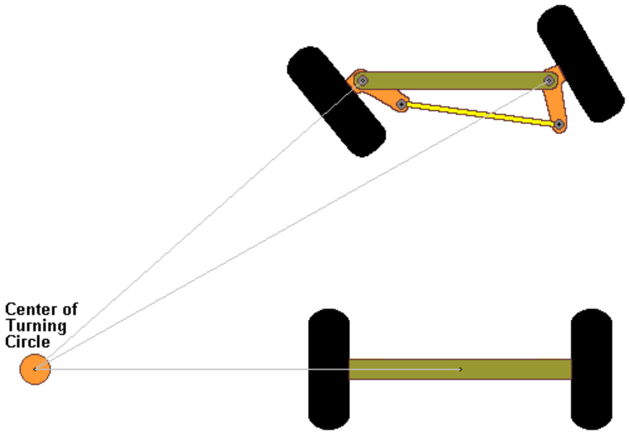
We are trying to mimic nature!

COMMON EFFECTORS FOR PROPULSION

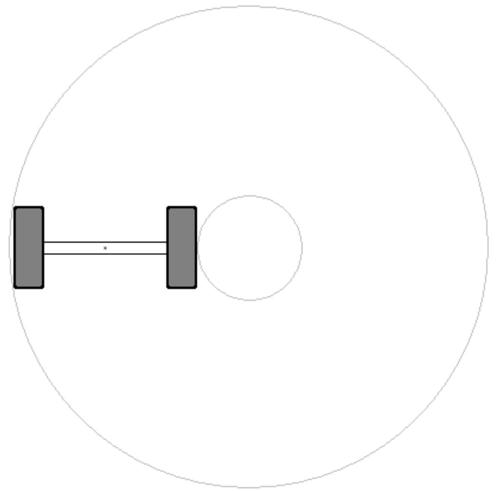
Wheels!

- Linear motion – easy: set left and right wheel speed equal
- Turning – several approaches:

Car-like

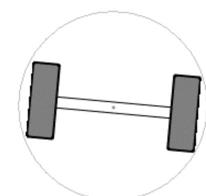


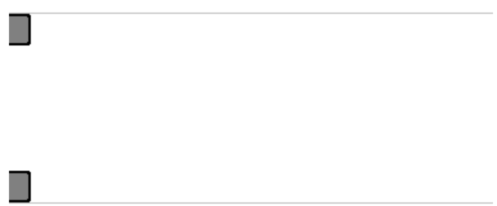
Differential

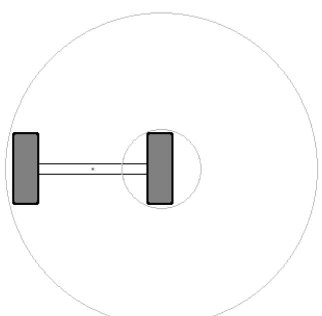


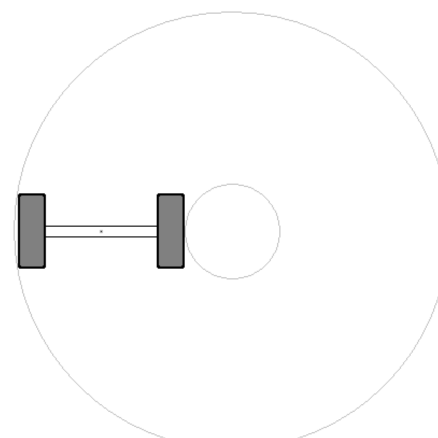
DIFFERENTIAL STEERING

- Very common technique for mobile robots
- Turning by changing the relation between v_l and v_r (speed of left and right wheel)
- The Kompai robot is controlled by specifying linear velocity v and angular (rotational) velocity ω.
- ω (radians/seconds) is the rate of change of the heading of the robot
- v_l and v_r are automatically controlled by the robot









MORE ON SENSORS

- Interaction with the environment is what makes Robotics special
- Sensors are essential!
- We will try to answer the following questions:
    - What is a sensor?
    - What are the most typical sensors?
    - What is sensor fusion?

WHAT IS A SENSOR?

A sensor measures a particular *physical entity* that has a known relationship with *a property of the environment (or robot)*.

Example:

A speedometer in a car measures the number of revolutions of the wheels per unit of time.

- Assumption: the number of revolutions is proportional to the speed of the car.

WHICH PROPERTY OF THE ENVIRONMENT ?

- **Proximity sensors**: Direction and distance of objects around the robot

pose

- **Position sensors**: (x,y,z) for the robot
- **Attitude sensors**: (roll, pitch, yaw) for the robot
- **Speed**: Change in pose
- Ambient light level
- Temperature
- Identity of objects
- …

PROXIMITY SENSORS

PROXIMITY SENSORS

Delivers direction and distance to objects (obstacles, goals, ...)

Range sensors:

- Infrared (IR)
- Ultrasonic sonars (or simply Ultrasonics)
- Laser Scanner
- 3D Cameras

Contact sensors:

- Bump and tactile sensors

REFLECTIVE IR SENSORS

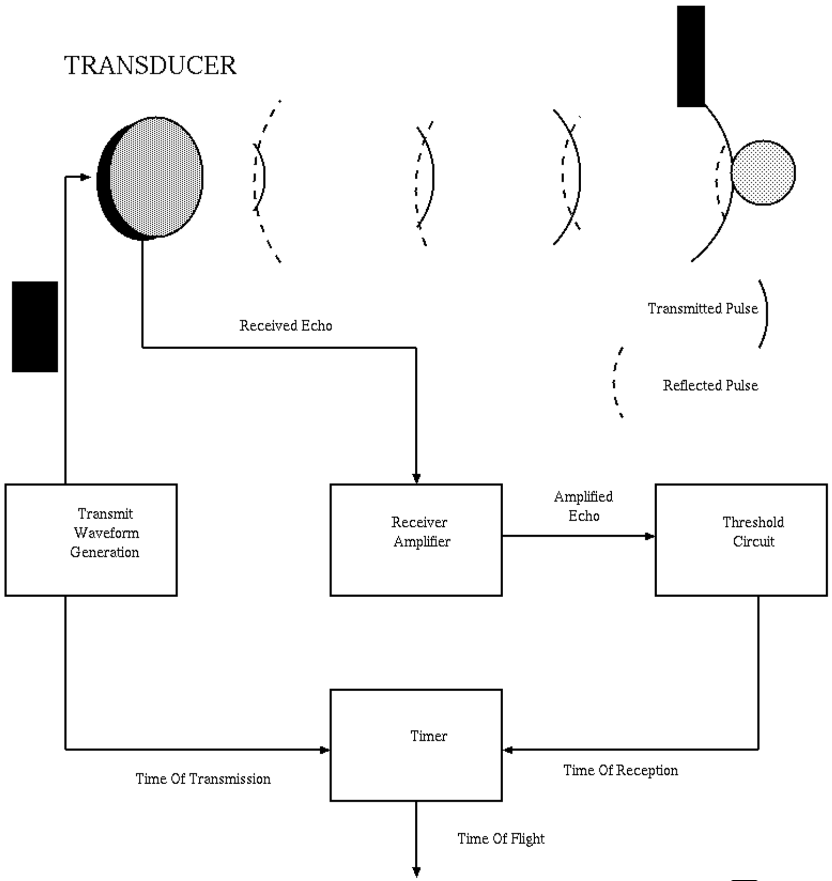
Physical entity

- Emits IR-light and measures the intensity of the reflexion
- Intensity ⇒ Distance
- Sensitive to ambient light
  - Solution: Modulated IR
- Sensitive to varying absorption of light
  - Depends on the material

Property of the environement

ULTRASONICS (SONAR)

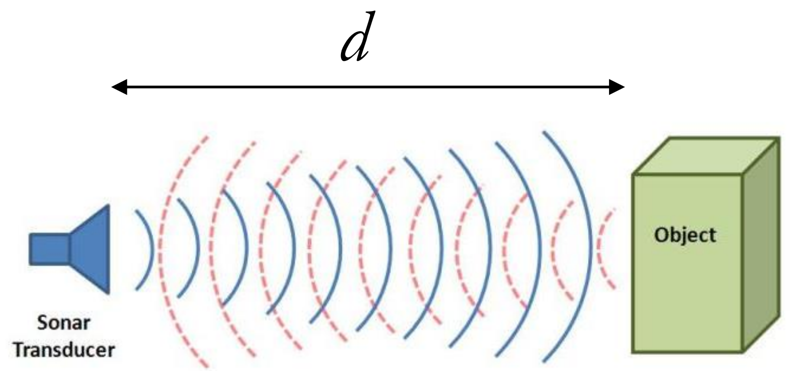
- Emits a 50 KHz "chirp" and "listens" for bounce back
- Determines range based on time of flight



DETERMINING DISTANCE *d* FROM TIME OF FLIGHT *t*

Property of the environement

Physical entity



Basic sonar illustration – a transducer generates a sound pulse and then listens for the echo.

$d = ½\, c\, t$

$c = c_o + 0.6\, T$

$c_o = 331\ m/s$

T : temperature in degrees Celsius

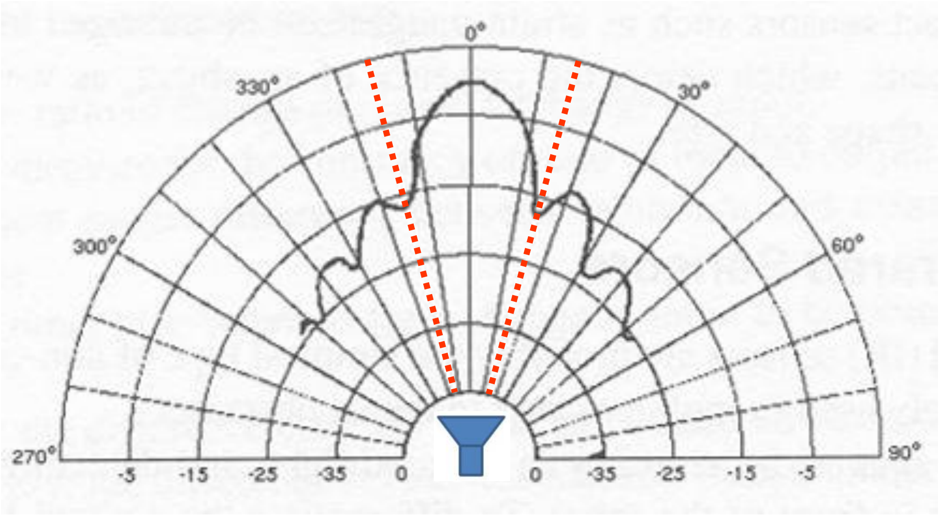
c_o : speed of sound at 0° Celsius

Given *d* : Where is the Object?

UMEÅ UNIVERSITY

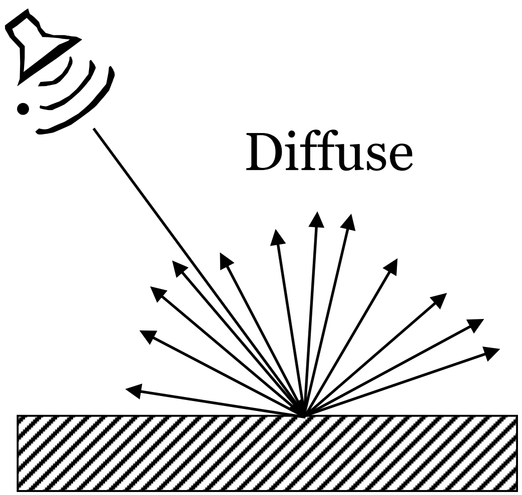
UNCERTAINTY IN ULTRASONIC SONARS

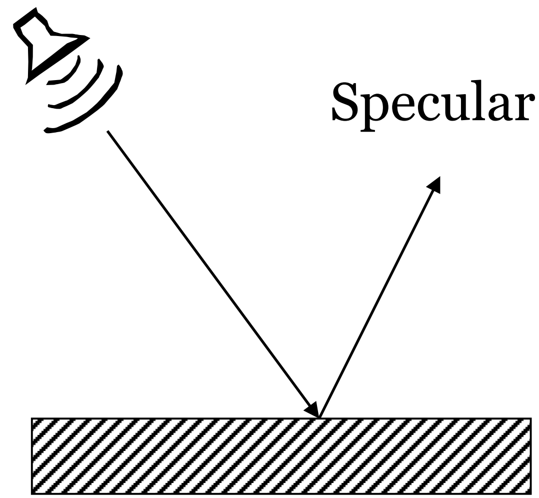
<u>Sensitivity</u> as a function of angle (logarithmic scale)



- The *main lobe* is pretty well defined as +/- 15°
- Assumption: all echoes come from the main lobe
- The exact location of the echo is still uncertain

TWO MAJOR KINDS OF REFLECTION



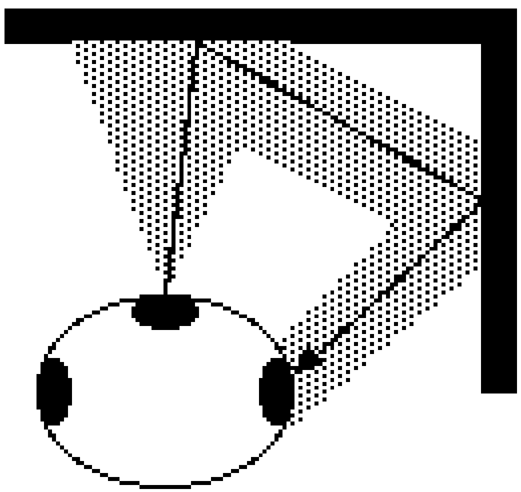


- Diffuse is ok:
  - High probability that an echo will return
- Specular is no good:
  - The sound may return later or not return at all. The former is harder to deal with.

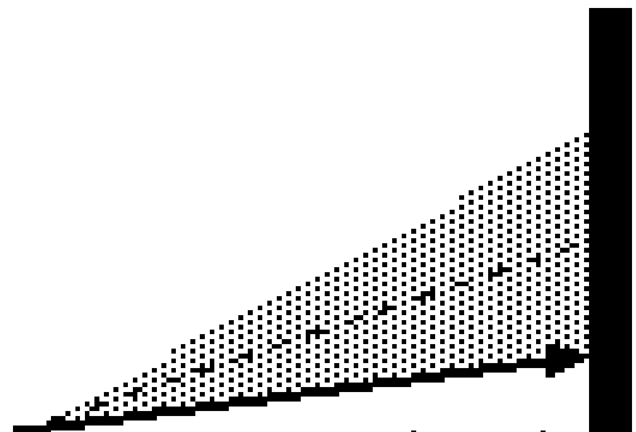
Hard shiny surfaces are problematic for sonars (and rough ones)

OTHER SOURCES OF UNCERTAINTY

Cross talk



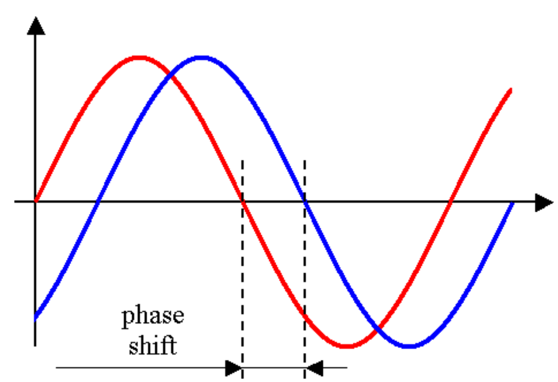
Foreshortening



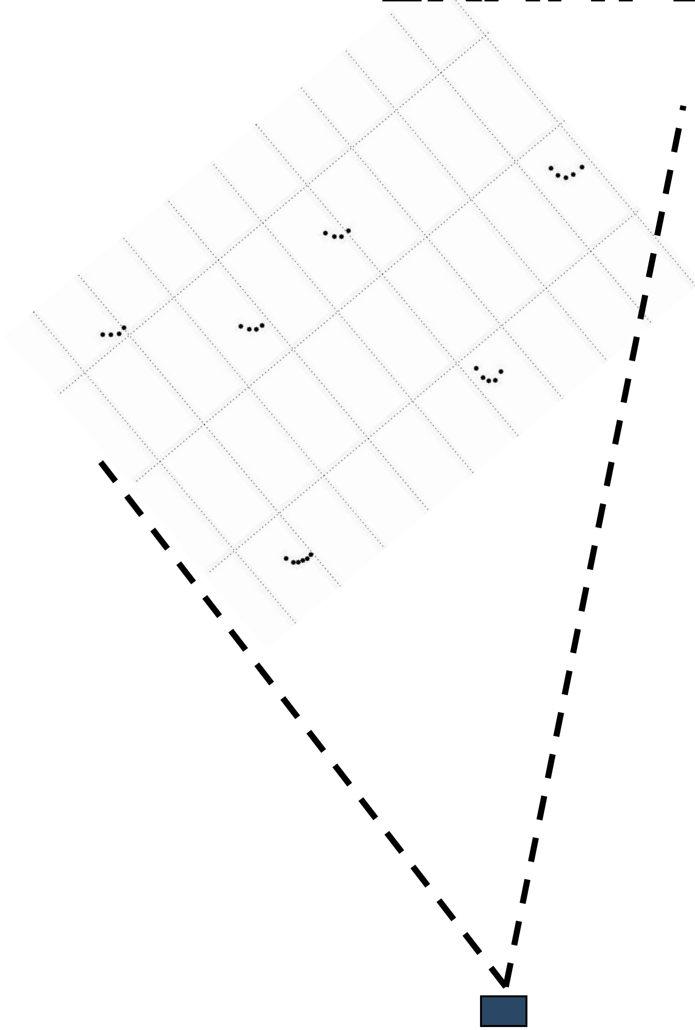
LASER SCANNER

Hokuyo
URG-04LX

- Ultrasonic sonars measures the time of flight for an emitted sound burst
- Same technique can be used with a laser beam
- But light is much faster
  - Still: Some laser scanners measure time of flight.
  - Easier to modulate the light and measure phase shift.
- A laser beam is much more narrow than a US main lobe
- In a laser scanner, beams are emitted by a rotating laser, and returns distances for each beam
- Usually harmless, invisible light!
- Specular reflection can still be a problem

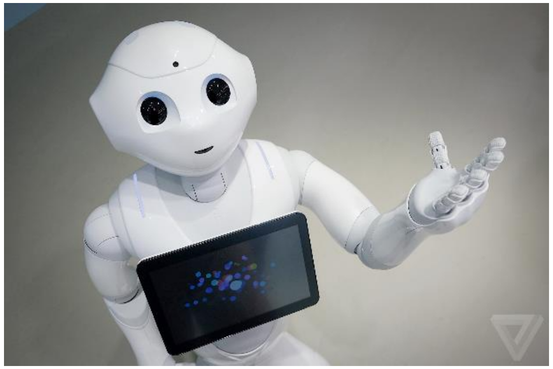


EXAMPLE OF LASER SCAN



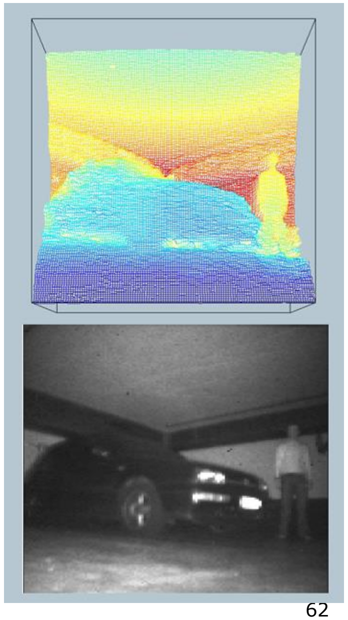
- A scan consists of 361 ranges, one for each 0.5 degree in 0..180.
- From angle and range, (x,y) can be computed

UMEÅ UNIVERSITY

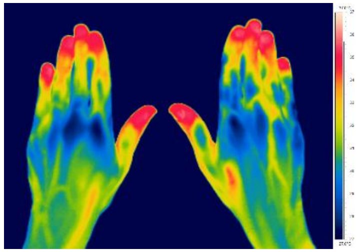


CAMERAS

- In many respects the most important sensor for humans and animals
- Enables detection, classification and localization of objects and environment
- RGB cameras are most common
- Some cameras extend the capabilities of the human eye
  - 3D cameras



  - Thermal cameras



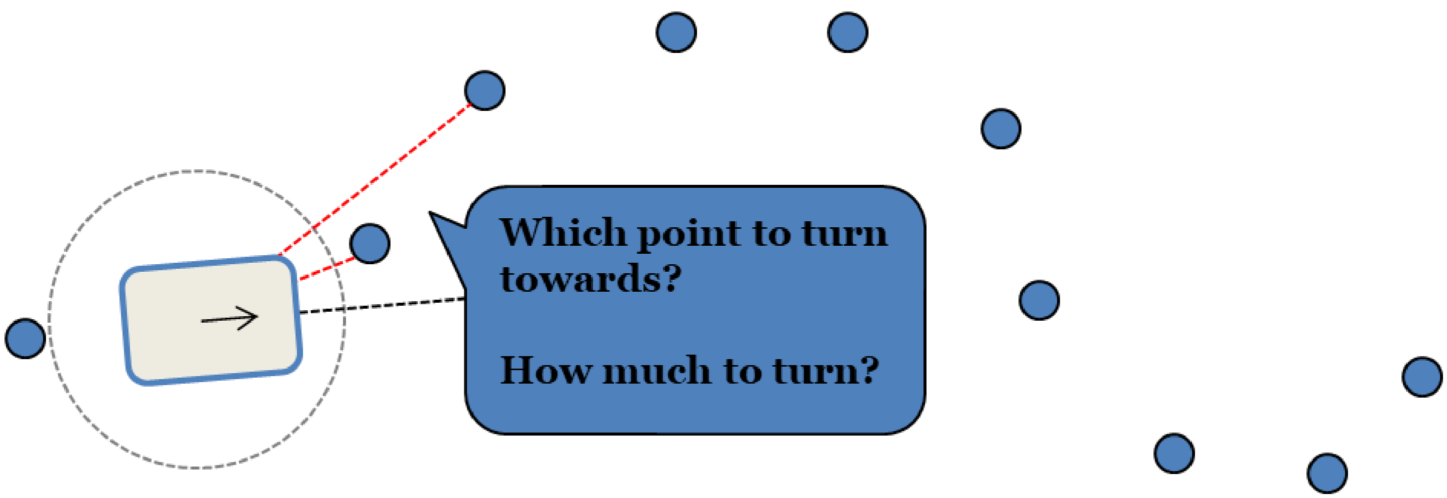
- Require complex image analysis

ASSIGNMENT 1: FOLLOW THE PATH

UMEÅ UNIVERSITY

FOLLOW THE PATH

- Create a program that controls the robot in a simulated environment such that the robot follows a specified path
  - Use Follow the Carrot or Pure Pursuit
  - See course planning on Canvas for some Math tips



FOLLOW THE PATH

- You will work with a simulated robot, in Microsoft Robotic Developer Studio 4 (MRDS)
  - Use the office environment
- Create a program that can read sensors of the robot, and post commands to it
  - Communicate with the robot over HTTP
  - Helper functions contain all low-level communications
  - Example programs: TestRobot3.py, TestRobot3.java
  - Python code also include plotting

EXAMINATION OF ASSIGNMENT 1

- Work in pairs, **demonstrate** your working solution **on Zoom**
  - You will get a new path for the demo
  - We will create a sign-up list on Canvas
- After the demonstration, **compare** your results to another group and write a **1 page report** about similarities/differences together
- Demo: 2020-09-16
- Report: 2020-09-17

NEXT LECTURE

- Next lecture: The intelligent agent with Andrea ☺

UMEÅ UNIVERSITY