Robots and

People

Vlad Estivill-Castro (2016)

Robots for People

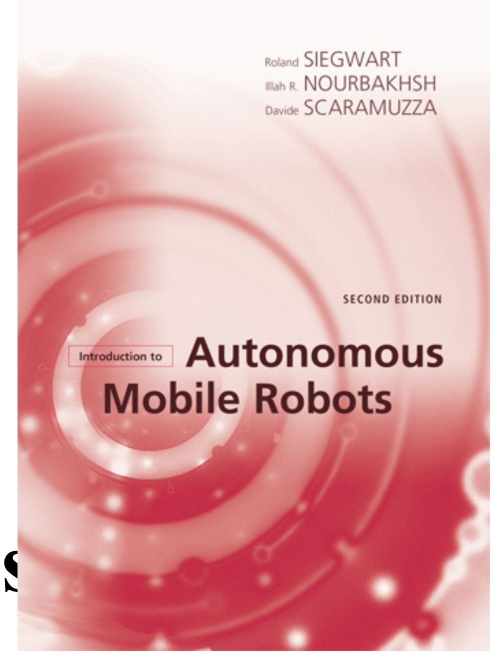
--- A project for intelligent integrated systems

Perception Concepts

Sensors (not vision)

Section 4.1(textbook)

What is the course about?



Roland SIEGWART
Illah R. NOURBAKHSH
Davide SCARAMUZZA

SECOND EDITION

Introduction to Autonomous Mobile Robots

- textbook
- **Introduction to Autonomous Robots**
- second edition
  Roland Siegwart, Illah R. Nourbakhsh, and Davide Scaramuzza

Sensors for Mobile robots

- Why should a robotics engineer know about sensors?
  - They are the **key components** for perceiving the environment
  - **Understanding the physical principles** enables appropriate use
- Understanding the physical principle behind sensors enables us:
  - To **properly select** the sensors for a given application
  - To **properly model** the sensor system, e.g. resolution, bandwidth, **uncertainties**

Sensors (what)

- Physical devices that provide information about the world
- Based on the source of the received stimuli we have:
  - **Proprioception**: sensing internal state - stimuli arising from within the agent (e.g., muscle tension, limb position)
  - **Exteroception**: sensing external state – external stimuli (e.g., vision, audition, smell, etc.)
- The ensemble of **proprioceptive** and **exteroceptive** sensors constitute the robot' s perceptual system

Sensor Examples

Physical Property	Sensor
contact	switch
distance	ultrasound, radar, infrared
light level	photocells, cameras
sound level	microphone
rotation	encoders and potentiometers
acceleration	accelerometers gyroscopes

More Sensor Examples

Physical Property	Sensor
magnetism	compass
smell	chemical
temperature	thermal, infra red
inclination	inclinometers, gyroscopes
pressure	pressure gauges
altitude	altimeters
strain	strain gauges

Knowing what's Going On

- Perceiving environmental state is crucial for the survival or successful achievement of goals
- Why is this hard?
    - Environment is dynamic
    - Only partial information about the world is available
    - Sensors are limited and noisy
    - There is a lot of information to be perceived
- Sensors do not provide **state**
- Sensors are physical devices that measure physical quantities

Dealing with real world situations

- Reasoning about a situation
- Cognitive systems have to interpret situations based on uncertain and only partially available information
- They need ways to learn functional and contextual information (semantics / understanding)
    - PROBABILISTIC REASONING

Types of Sensors

- Sensors provide raw measurements that need to be processed
- Depending on how much information they provide, sensors can be simple or complex
- Simple sensors:
  - A switch: provides 1 bit of information (on, off)
- Complex sensors:
  - A camera: 512x512 pixels
  - Human retina: more than a hundred million photosensive elements

Types of Sensors (how)

- Passive sensors
  - Measure energy coming from the environment
- Active sensors
  - emit their proper energy and measure the reaction
  - better performance, but some influence on environment

Getting Answers From Sensors

- Given a sensory reading, what should I do?
  - Deals with **actions** in the world
- Given a sensory reading, what was the world like when the reading was taken?
  - Deals with **reconstruction** of the world
- Simple sensors can answer the first question
  - Their output can be used directly
- Complex sensors can answer both questions
  - Their information needs to be processed

Signal to Symbol Problem

- Sensors produce only signals, not symbolic descriptions of the world
- To extract the information necessary for making intelligent decisions a lot of **sensor pre-processing** is needed
  - Symbols are abstract representations of the sensory data
- Sensor pre-processing
  - Uses methods from electronics, signal processing and computation

Levels of Processing

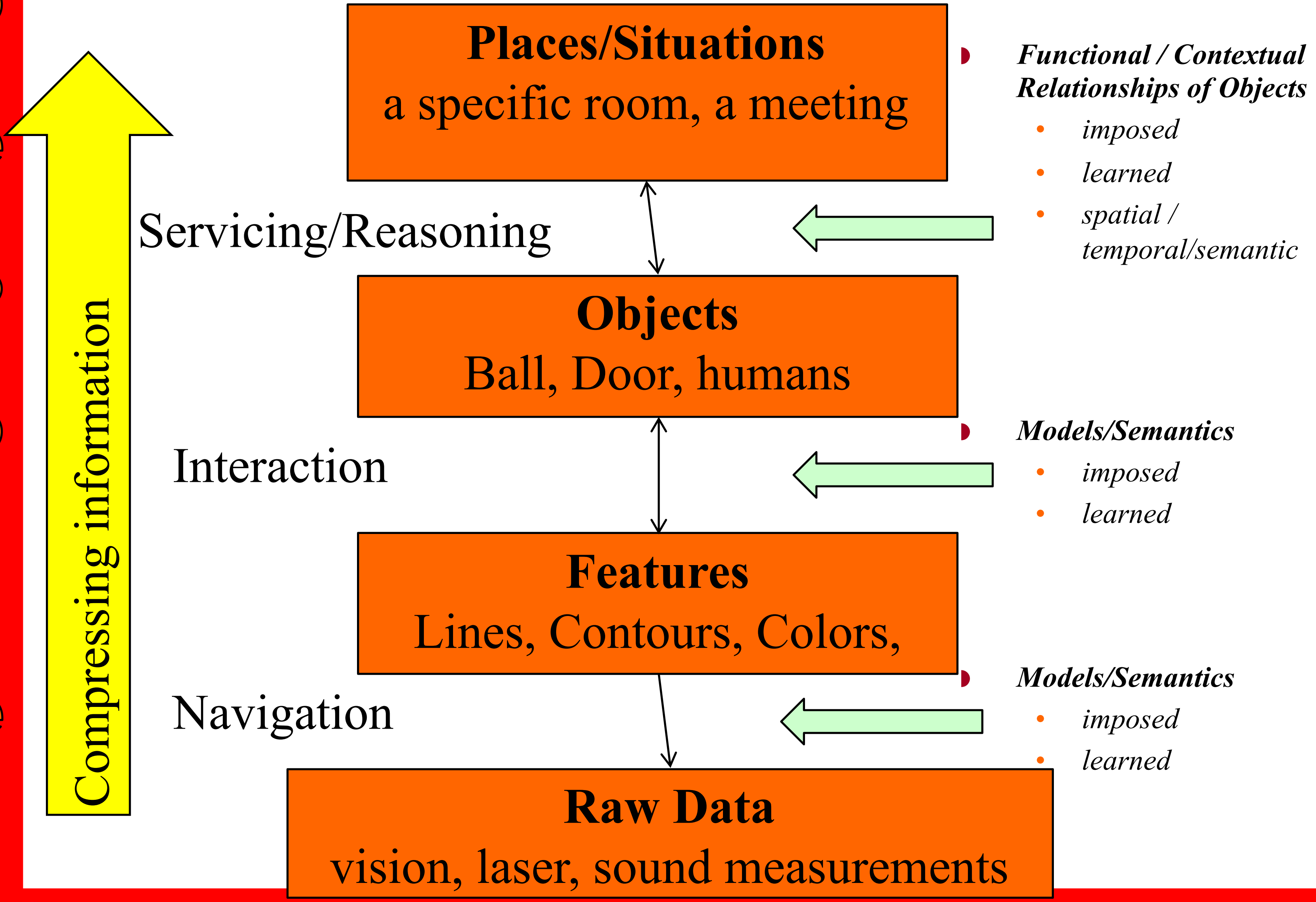
- Finding out if a switch is open or closed
  - Measure voltage going through the circuit ⇒ **electronics**
- Using a microphone to recognize voice
  - Separate signal from noise, compare with store voices for recognition ⇒ **signal processing**
- Using a surveillance camera
  - Find people in the image and recognize intruders, comparing them to a large database ⇒ **computation**

Perception Requirements

Perception requires more than just sensors:

- Sensors
  - Power and electronics
- Computation
  - More power and electronics
- Connectors
  - To connect it all

Perception for Mobile Robots



Compressing information

Places/Situations
a specific room, a meeting

Servicing/Reasoning

Objects
Ball, Door, humans

Interaction

Features
Lines, Contours, Colors,

Navigation

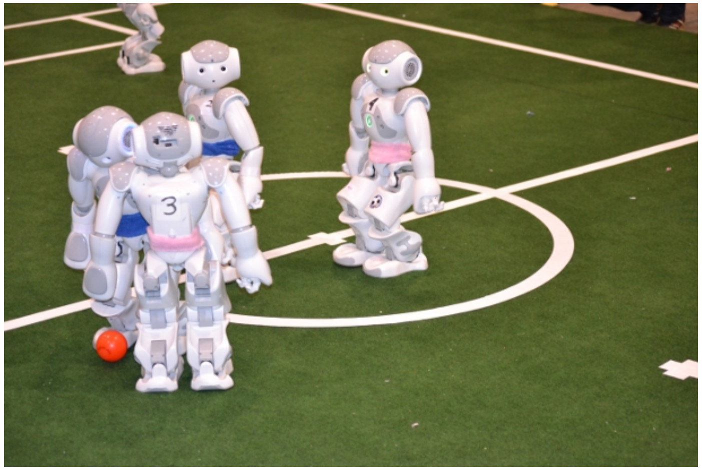
Raw Data
vision, laser, sound measurements

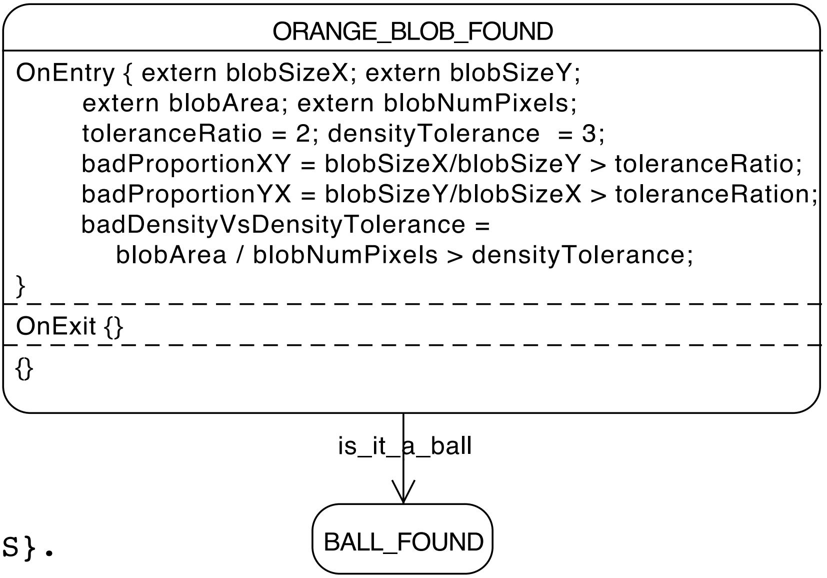
- ***Functional / Contextual Relationships of Objects***
  - *imposed*
  - *learned*
  - *spatial / temporal/semantic*

- ***Models/Semantics***
  - *imposed*
  - *learned*

- ***Models/Semantics***
  - *imposed*
  - *learned*

Example from robotic soccer



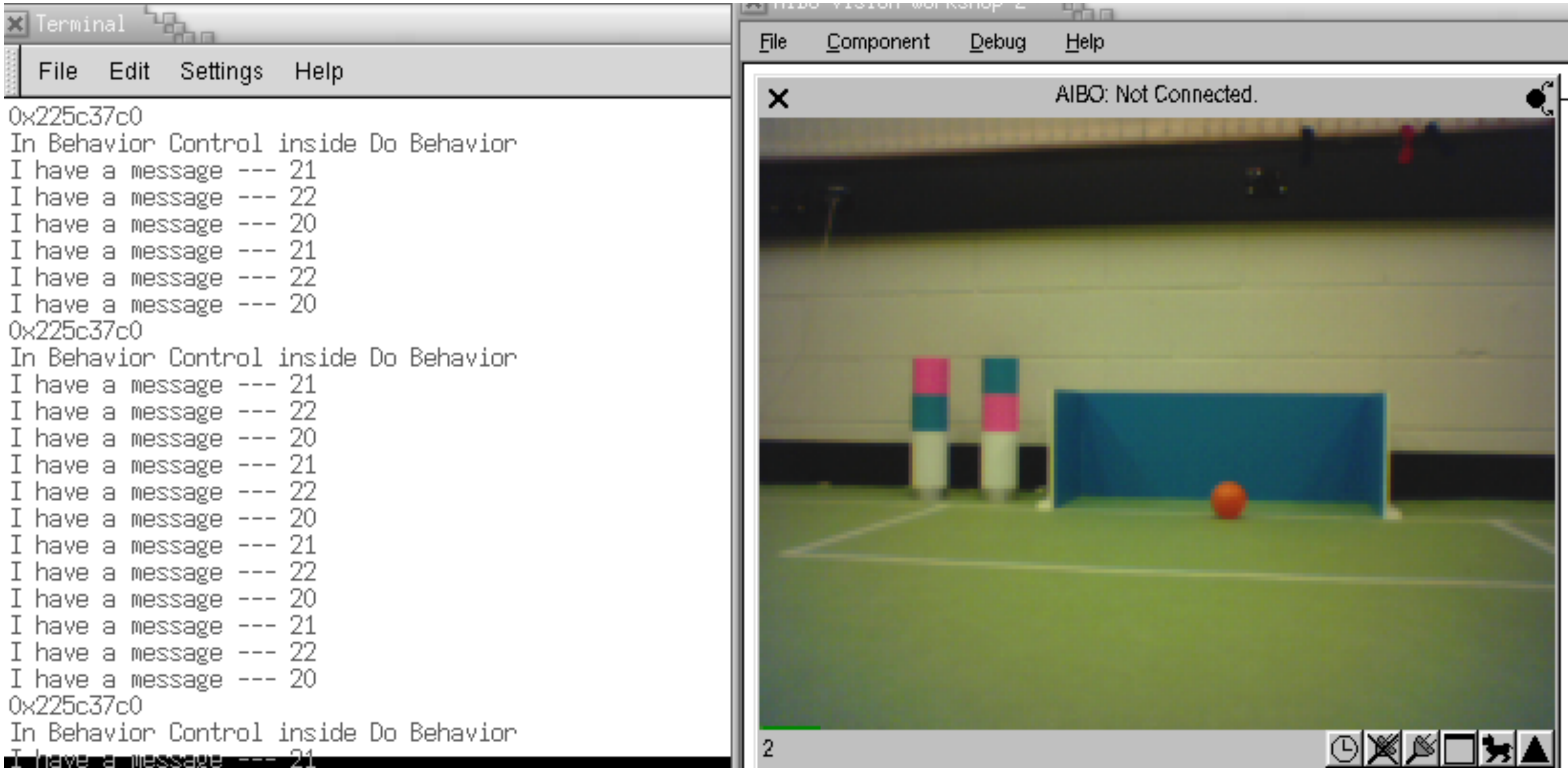


ORANGE_BLOB_FOUND

```
OnEntry { extern blobSizeX; extern blobSizeY;
      extern blobArea; extern blobNumPixels;
      toleranceRatio = 2; densityTolerance  = 3;
      badProportionXY = blobSizeX/blobSizeY > toleranceRatio;
      badProportionYX = blobSizeY/blobSizeX > toleranceRation;
      badDensityVsDensityTolerance =
         blobArea / blobNumPixels > densityTolerance;
}
OnExit {}
{}
```

```
% BallConditions.d

name{BALLCONDITIONS}.

input{badProportionXY}.
input{badProportionYX}.
input{badDensityVsDensityTolerance}.

BC0: {}              => is_it_a_ball.
BC1: badProportionXY  =>  ~is_it_a_ball. BC1 > BC0.
BC2: badProportionYX  =>  ~is_it_a_ball. BC2 > BC0.
BC3: badDensityVsDensityTolerance  =>  ~is_it_a_ball. BC3 > BC0.

output{b is_it_a_ball, "is_it_a_ball"}.
```

Illustration



```
0x225c37c0
In Behavior Control inside Do Behavior
I have a message --- 21
I have a message --- 22
I have a message --- 20
I have a message --- 21
I have a message --- 22
I have a message --- 20
0x225c37c0
In Behavior Control inside Do Behavior
I have a message --- 21
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I have a message --- 22
I have a message --- 20
I have a message --- 21
I have a message --- 22
I have a message --- 20
I have a message --- 21
I have a message --- 22
I have a message --- 20
0x225c37c0
In Behavior Control inside Do Behavior
I have a message --- 21
```
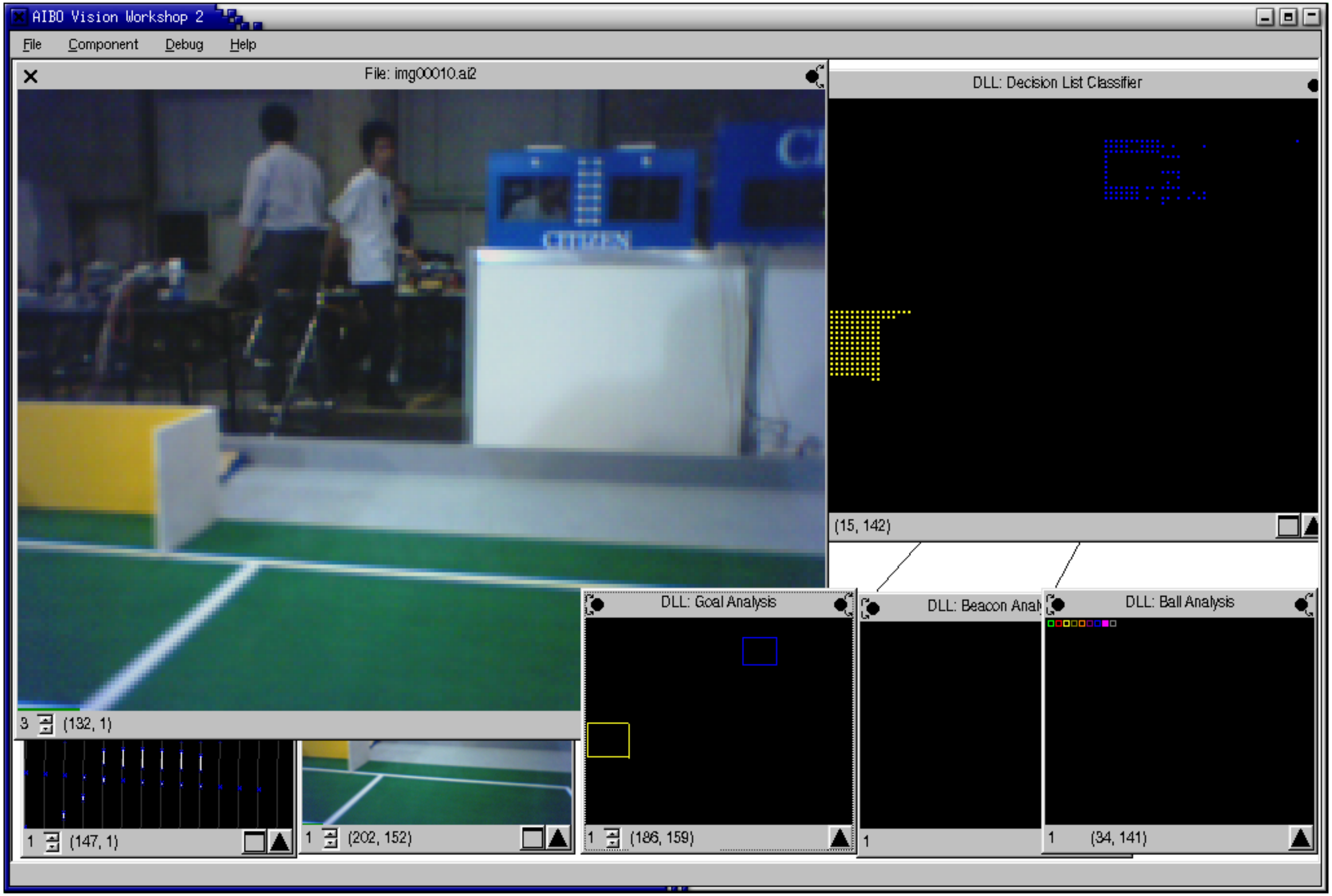
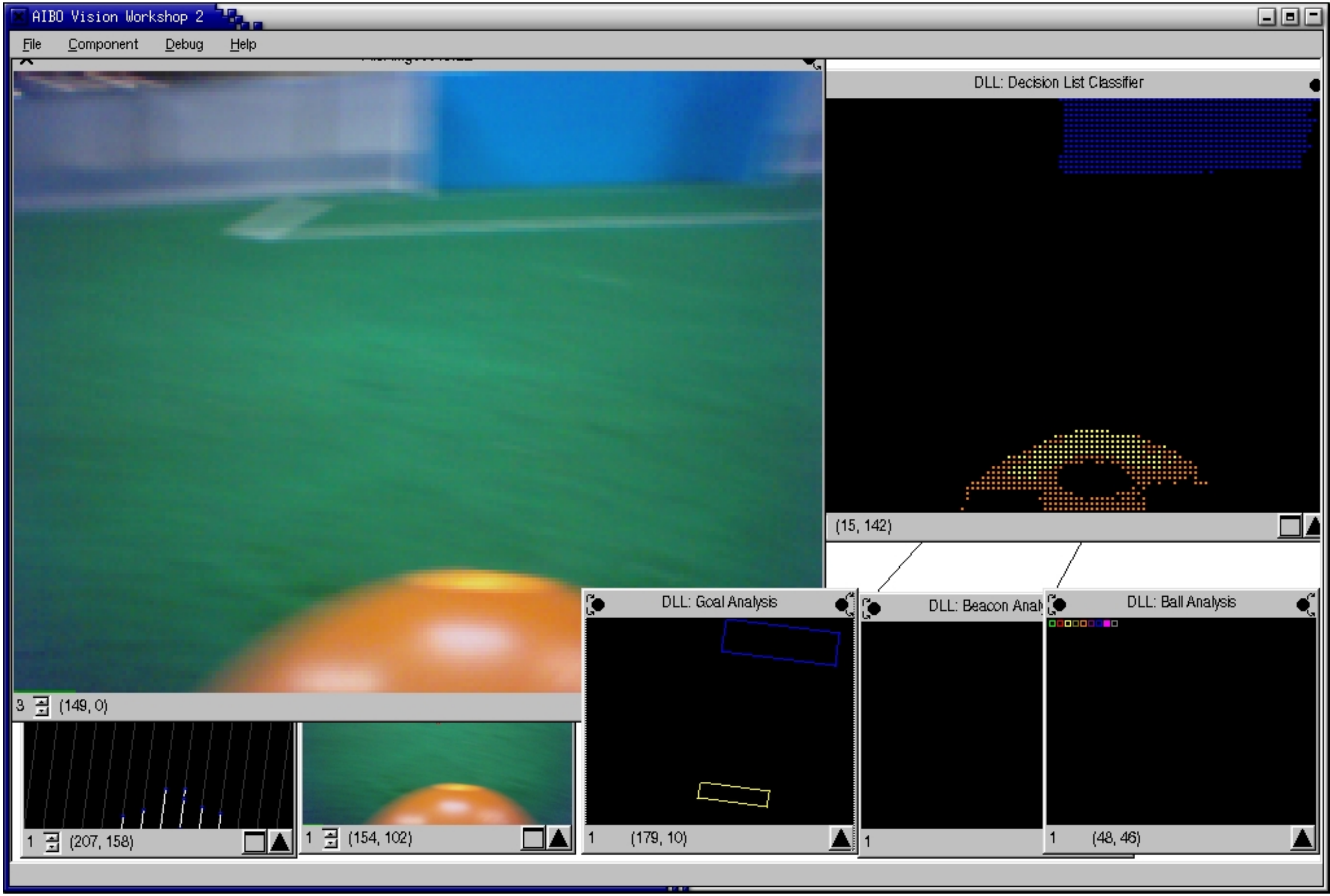
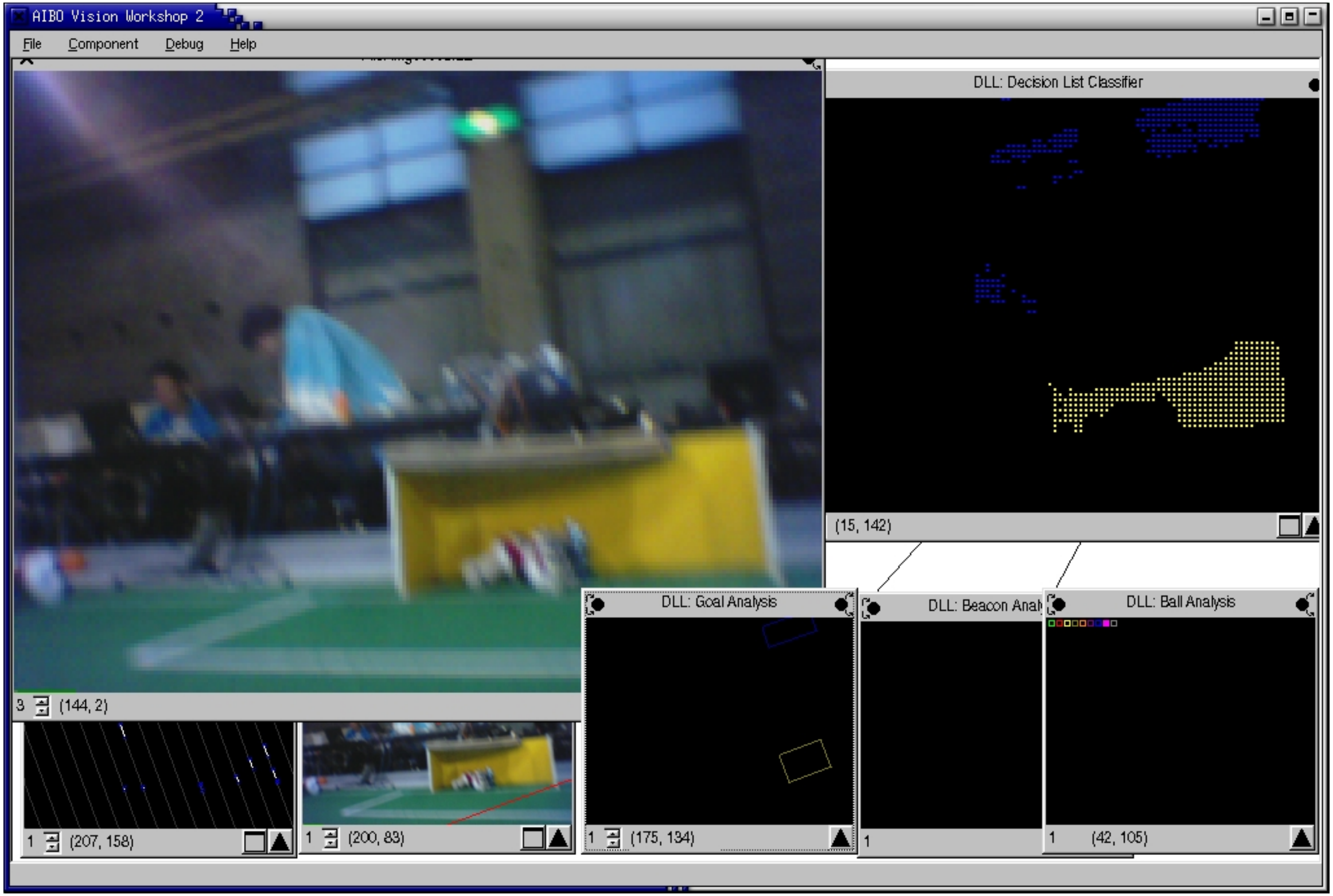

The left post and goal appear in the correct order, but the right post appears left most

The module in action



Robots and people




AIBO Vision Workshop 2
File
Component
Debug
Help
DLL: Decision List Classifier
(15, 142)
3
(144, 2)
1
(207, 158)
1
(200, 83)
DLL: Goal Analysis
1
(175, 134)
DLL: Beacon Anal
1
DLL: Ball Analysis
1
(42, 105)

Characterizing Sensor Performance –(1)

- Dynamic range
  - **ratio between upper and lower limits**, usually in decibels (dB, power)
  - e.g. power measurement from 1 mW to 20 W
    - 10 *log* [20 /0.001] = 43 dB
  - e.g. voltage measurement from 1 mV to 20 V
    - 20 log [20/0.001] = 86 dB
      - – Since $P= U I = U^2 /R$
      - – 20 instead of 10 because square of voltage is equal to power

Characterizing Sensor Performance –(2)

- Range
  - **upper limit - lower limit**
- Resolution
  - **minimum difference between two values**
  - usually: lower limit of dynamic range = resolution
  - for digital sensors it is usually the A/D resolution.
    - e.g. 5V / 255 (8 bit)
- Linearity
  - variation of output signal as function of the input signal
  - linearity is less important when signal is treated with a computer
    - $f(ax + by) = a\,f(x) = b\,f(y)$

Characterizing Sensor Performance –(3)

- Bandwidth or Frequency
  - **the speed with which a sensor can provide a stream of readings**
  - usually there is an upper limit depending on the sensor and the sampling rate
  - lower limit is also possible, e.g. acceleration sensor
  - one has also to consider phase (delay) of the signal

In Situ Performance (1)

- Sensitivity
  - ratio of output change to input change dx/dy
  - however, in real world environment, the sensor has often high sensitivity to other environmental changes, i.e. illumination
- Cross-sensitivity (and cross-talk)
  - sensitivity to other environment parameters (temperature, magnetic field)
- Error/Accuracy
  - difference between the sensor's output and the true value
    - accuracy = $(1- |m-v|/v)$ m=measurement; v=value

In Situ Performance (1)

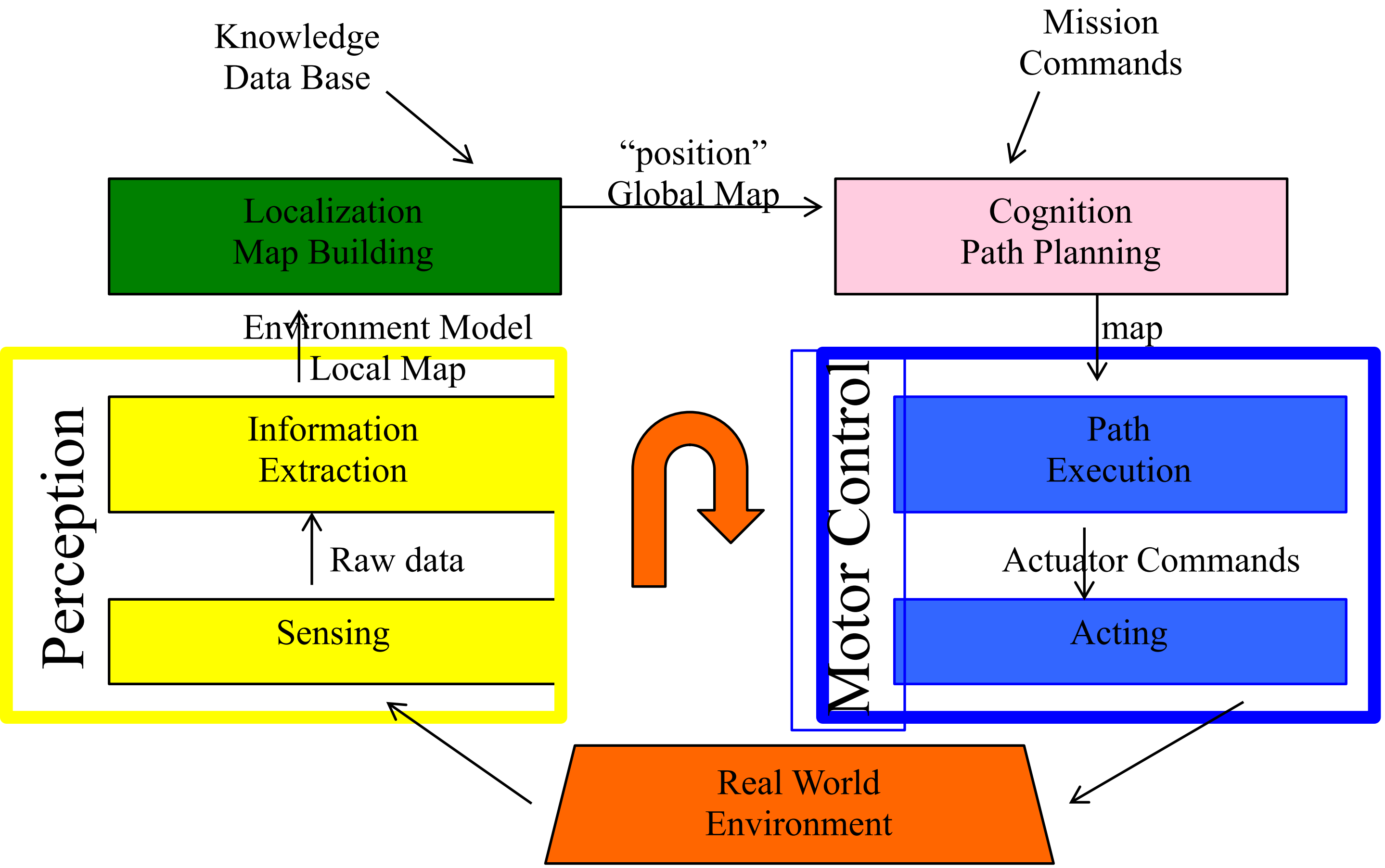
- Systematic error -> deterministic errors
  - caused by factors that can (in theory) be modeled -> prediction
    - e.g. a calibration of a laser sensor of the distortion caused by optics of a camera
- random error -> non-deterministic
  - no prediction possible with given sensors
    - however, they can be described probabilistically
- precision
  - reproducibility of sensor results
    - precision = range /σ

Perception Designs

- Historically perception has been treated in isolation
  - perception in isolation
  - perception as “king”
  - perception as reconstruction
- Generally it is not a good idea to separate:
  - What the robot senses
  - How it senses it
  - How it processes it
  - How it uses it

General Control Scheme for Mobile Robot Systems

- (Roland Siegwart, Illah Nourbakhsh, Davide Scaramuzza)



A Better Way

- Instead it is good to think about it as a single complete design
  - The **task** the robot has to perform
  - The best suited **sensors** for the task
  - The best suited **mechanical design** that would allow the robot to get the necessary sensory information for the task (e.g. body shape, placement of the sensors)
- EXAMPLE: Robotic guides in museums

A New Perceptual Paradigm

Perception without the context of actions is meaningless

- Action-oriented perception

  How can perception provide the information necessary for behavior?

  - Perceptual processing is tuned to meet motor activity needs
  - World is viewed differently based on the robot's intentions
  - Only the information necessary for the task is extracted
- Active perception

  How can motor behaviors support perceptual activity?

  - Motor control can enhance perceptual processing
  - Intelligent data acquisition, guided by feedback and a priori knowledge

Using A Priori Knowledge of the World

- Perceptual processing can benefit if knowledge about the world is available
  - Expectation-based perception (what to look for)
    - Knowledge of the world constraints the interpretation of sensors
  - Focus of attention methods (where to look for it)
    - Knowledge can constrain where things may appear
  - Perceptual classes (how to look for it)
    - Partition the world into categories of interaction

Sensor Fusion

A man with a watch knows what time it is;

a man with two watches isn't so sure

- Combining multiple sensors to get better information about the world
- Sensor fusion is a complex process
  - Different sensor accuracy
  - Different sensor complexity
  - Contradictory information
  - Asynchronous perception
- Cleverness is needed to put this information together

Neuroscientific Evidence

- Our brain process information from multiple sensory modalities
  - Vision, touch, smell, hearing, sound
- Individual sensory modalities use separate regions in the brain (sight, hearing, touch)
- Vision itself uses multiple regions
  - Two main vision streams: the "what" (object recognition) and the "where" (position information)
  - Pattern, color, movement, intensity, orientation

What Can We Learn from Biology?

Sensor function should decide its form

- Evolved sensors have specific geometric and mechanical properties
- Examples
    - Flies: complex facetted eyes
    - Birds: polarized light sensors
    - Bugs: horizon line sensors
    - Humans: complicated auditory systems
- Biology uses clever designs to maximize the sensor's perceptual properties, range and accuracy

Psychological Insights: Affordances

- **Affordances**: refer to the meaning of objects in relation to an organism’s motor intents
- Perceptual entities are not semantic abstractions, but opportunities that the environment presents
- Perception is biased by the robot’s task
    - A chair:
        - Something to sit in
        - Something blocking the way
        - Something to throw if attacked

Robots and People

How Would You Detect People?

- Use the interaction with the world, keep in mind the task
  - Camera: great deal of processing
  - Movement: if everything else is static: movement means people
  - Color: If you know the particular color people wear
  - Temperature: can use sensors that detect the range of human body heat
  - Distance: If any open-range becomes blocked

Entrapment

- http://www.youtube.com/watch?v=UxVP5PFI9b8

How Would You Measure Distance?

- Ultrasound sensors (sonar) provide distance measurement directly (time of flight)
- Infra red sensors provide return signal intensity
- Two cameras (i.e., stereo) can be used to compute distance/depth
- A laser and a camera:
- Laser-based structured light: overly grid patterns on the world, use distortions to compute distance

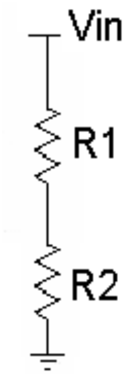
Sensor Categories

- Passive Sensors
  - Measure a physical property from the environment
- Active Sensors
  - Provide their own signal and use the interaction of the signal with the environment
  - Consist of an emitter and a detector
- Sensor complexity
  - Determined by the amount of processing required
- Active/passive
  - Determined by the sensor mechanism

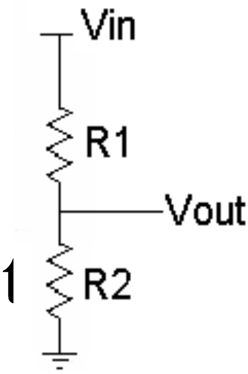
Electronics for Simple Sensors

- Ohm' s law **$V = IR$**
  - Explains the relationship between voltage current (I) and resistance (R)

- Series resistance **$V_{in} = I(R_1 + R_2)$**
  - Resistances in series add up

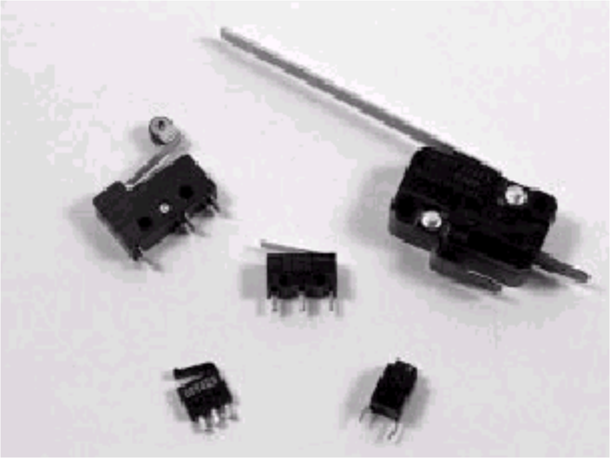


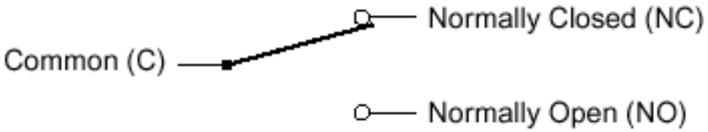
- Voltage divider
  - Voltage can be divided by using two resist in series **$V_{out} = V_{in} R_2/(R_1 + R_2)$**



Switch sensors

- Among the simplest sensors of all
- Do not require processing, work at "circuit" level
- If the switch is open there is no current flowing
- If the switch is closed ⇒ current will flow
- Can be
  - Normally open (more common)
  - Normally closed





Uses of Switch Sensors

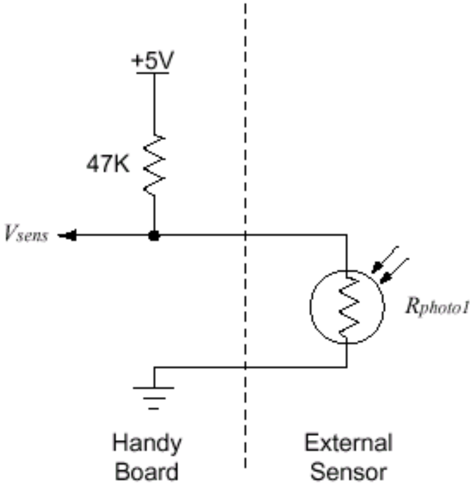
- Contact sensors:
  - detect contact with another object (e.g., triggers when a robot hits a wall or grabs an object, etc.)
- Limit sensors:
  - detect when a mechanism has moved to the end of its range (e.g., triggers when a gripper is wide open)
- Shaft encoder sensors:
  - detect how many times a shaft turns (e.g., a switch clicks at every turn, clicks are counted)

Example of Switch Uses

- In everyday life
  - Light switches, computer mouse, keys on the keyboard, buttons on the phone
- In robotics
  - Bump switch: detect hitting an obstacle
  - Whisker:
    1. Attach a long metal whisker to a switch; when the whisker has bent enough the switch will close
    2. Place a conductive wire (whisker) inside a metal tube; when the whisker bends it touches the tube and closes the circuit

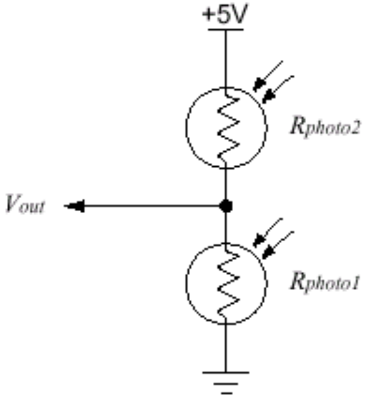
Light Sensors

- Light sensors measure the amount of light impacting a photocell
- The sensitivity of the photocell to light is reflected in changes in resistance
  - Low when illuminated V_{sens}
  - High when in the dark: V_{sens}
- Light sensors are "dark" sensors
- Could invert the output so that low means dark and high means bright



Uses of Light Sensors

- Can measure the following properties
  - Light intensity: how light/dark it is
  - Differential intensity: difference between photocells
  - Break-beams: changes in intensity
- Photocells can be shielded to improve accuracy and range



Differential Photocell Sensor

$R_{photo2} = R_{photo1}$

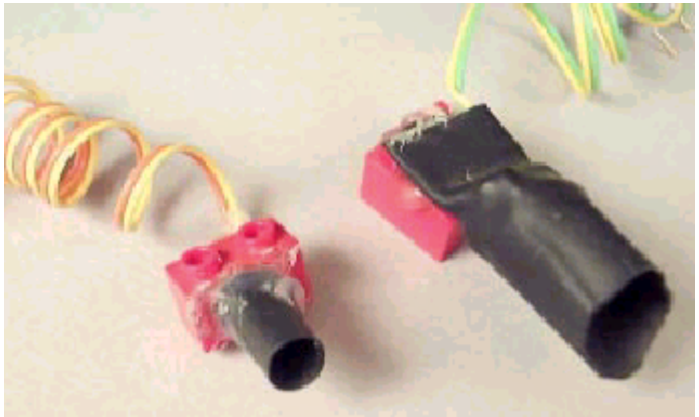
$V_{out} = 2.5$ v

$R_{photo2} << R_{photo1}$

$V_{out} \sim= +5$ v (R2 more light)

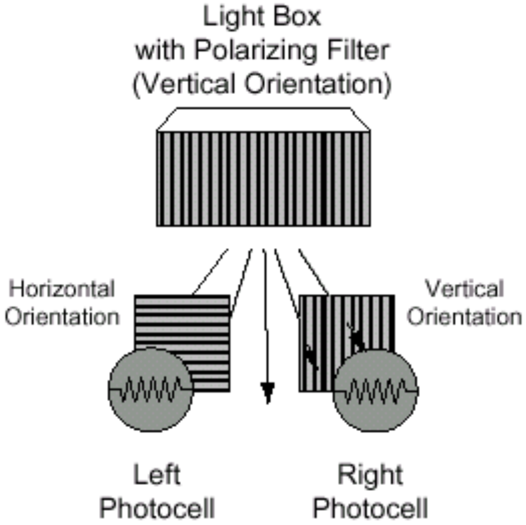
$R_{photo2} >> R_{photo1}$

$V_{out} \sim=$ gnd



Polarized Light

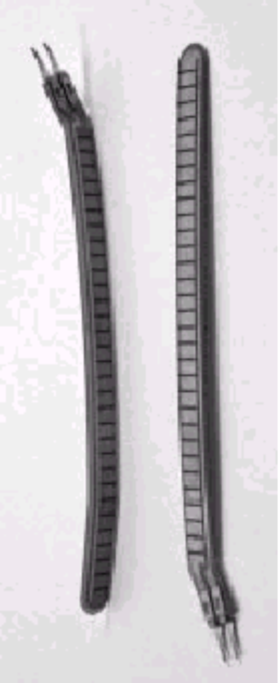
- Waves in normal light travel in all directions
- A polarizing filter will only let light in a specified direction ⇒ polarized light
- Why is it useful?
  - Distinguish between different light sources
  - Can tell if the robot is pointed at a light beacon
  - One photocell will receive only ambient light, while the other receives both ambient and source light
  - In the absence of filters both photocells would receive the same amount of light



Polarized Light Sensors

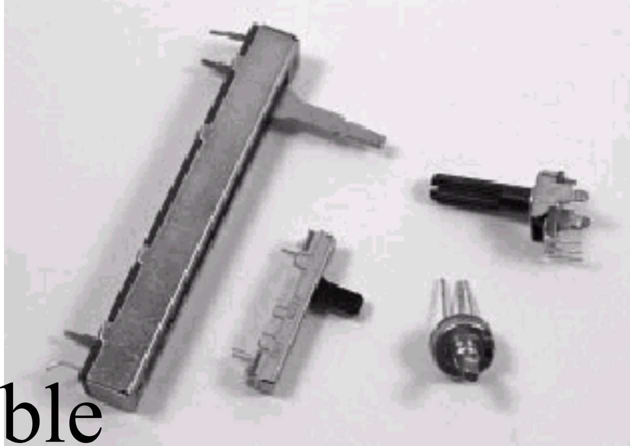
- Filters can be combined to select various directions and amounts of light
- Polarized light can be used by placing polarizing filters:
  - at the output of a light source (emitter)
  - at the input of a photocell (receiver)
- Depending on whether the filters add (pass through) or subtract (block) the light, various effects can be achieved

Resistive Position Sensors

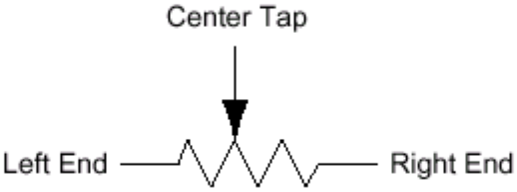


- Finger flexing in Nintendo PowerGlove
- In robotics: useful for contact sensing and wall-tracking
- Electrically, the bend sensor is a simple resistance
- The **resistance** of a material increases as it is bent
- The bend sensor is less robust than a light sensor, and requires strong protection at its base, near the electrical contacts
- Unless the sensor is well-protected from direct forces, it will fail over time

Potentiometers



- Also known as “pots”
- Manually-controlled variable resistor, commonly used as volume/tone controls of stereos
- Designed from a movable tab along two ends
- Tuning the knob adjusts the resistance of the sensor



Biological Analogs

- All of the sensors we have seen so far exist in biological systems
- Touch/contact sensors with much more precision and complexity in all species
- Polarized light sensors in insects and birds
- Bend/resistance receptors in muscles
- and many more..

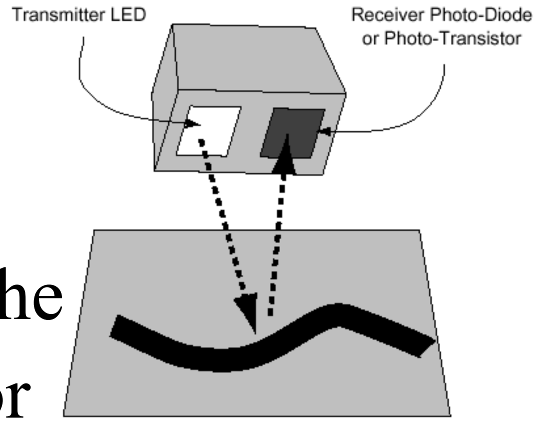
Active Sensors

Active sensors provide their own signal/stimulus (and thus the associated source of energy)

- reflectance
- break-beam
- infra red (IR)
- ultrasound (sonar)
- others

Reflective Optosensors

- Include a source of light **emitter** (light emitting diodes LED) and a light **detector** (photodiode or phototransistor)
- Two arrangements, depending on the positions of the emitter and detector
  - Reflectance sensors: Emitter and detector are side by side; Light reflects from the object back into the detector
  - Break-beam sensors: The emitter and detector face each other; Object is detected if light between them is interrupted



Photocells vs. Phototransistors

- Photocells
  - easy to work with, electrically they are just resistors
  - their response time is slow
  - suitable for low frequency applications (e.g., detecting when an object is between two fingers of a robot gripper)
- Reflective optosensors (photodiode or phototransistor)
  - rapid response time
  - more sensitive to small levels of light, which allows the illumination source to be a simple LED element

Reflectance Sensing

Used in numerous applications

- Detect the presence of an object
- Detect the distance to an object
- Detect some surface feature (wall, line, for following)
- Bar code reading
- Rotational shaft encoding

Properties of Reflectivity

- Reflectivity is dependent on the color, texture of the surface
  - Light colored surfaces reflect better
  - A matte black surface may not reflect light at all
- Lighter objects farther away seem closer than darker objects close by
- Another factor that influences reflective light sensors
  - Ambient light: how can a robot tell the difference between a stronger reflection and simply an increase in light in the robot' s environment?

Ambient light

- Ambient / background light can interfere with the sensor measurement
- To correct it we need to subtract the ambient light level from the sensor measurement
- This is how:
  - take two (or more, for increased accuracy) readings of the detector, one with the emitter on, one with it off,
  - then subtract them
- The result is the ambient light level

Calibration

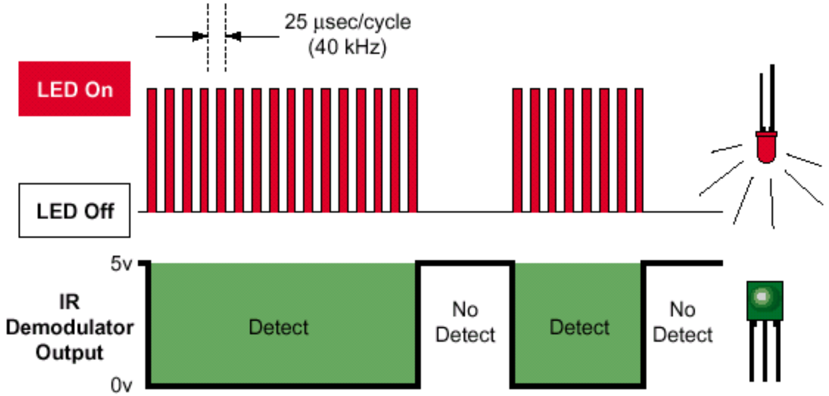
- The ambient light level should be subtracted to get only the emitter light level
- Calibration: the process of adjusting a mechanism so as to maximize its performance
- Ambient light can change ⇒ sensors need to be calibrated repeatedly
- Detecting ambient light is difficult if the emitter has the same wavelength
  - Adjust the wavelength of the emitter

Infra Red (IR) Light

- IR light works at a frequency different than ambient light
- IR sensors are used in the same ways as the visible light sensors, but more robustly
  - Reflectance sensors, break beams
- Sensor reports the amount of overall illumination,
  - ambient lighting and the light from light source
- More powerful way to use infrared sensing
  - Modulation/demodulation: rapidly turn on and off the source of light

Modulation/Demodulation

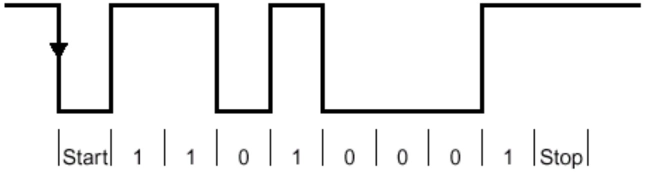
- Modulated IR is commonly used for communication



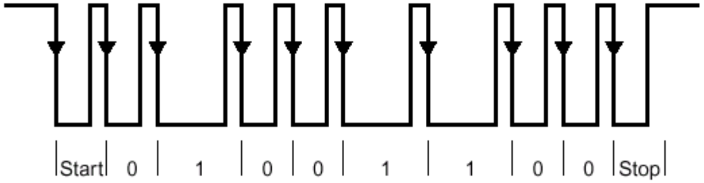
- Modulation is done by flashing the light source at a particular frequency
- This signal is detected by a demodulator tuned to that particular frequency
- Offers great insensitivity to ambient light
  - Flashes of light can be detected even if weak

Infrared Communication

- Bit frames
  - All bits take the same amount of time to transmit
  - Sample the signal in the middle of the bit frame
  - Used for standard computer/modem communication
  - Useful when the waveform can be reliably transmitted

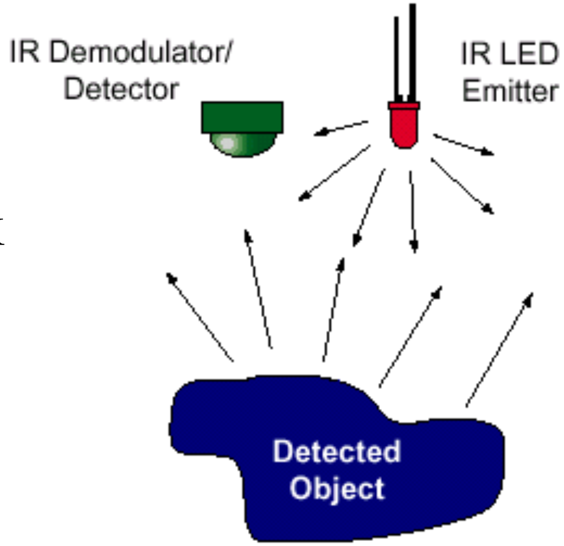


- Bit intervals
  - Sampled at the falling edge
  - Duration of interval between sampling determines whether it is a 0 or 1
  - Common in commercial use
  - Useful when it is difficult to control the exact shape of the waveform



Proximity Sensing

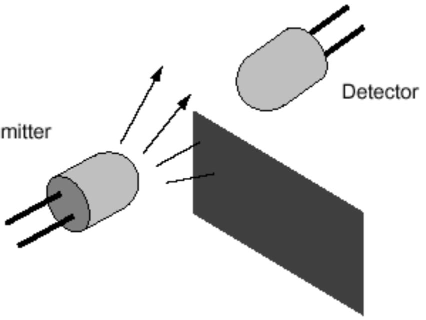
- Ideal application for modulated/demodulated IR light sensing
- Light from the emitter is reflected back into detector by a nearby object, indicating whether an object is present
  - LED emitter and detector are pointed in the same direction
- Modulated light is far less susceptible to environmental variables
  - amount of ambient light and the reflectivity of different objects

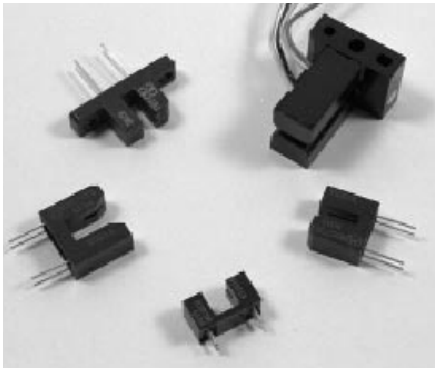


How does the wii work?

Break Beam Sensors

- Any pair of compatible emitter-detector devices can be used to make a break-beam sensor
- Examples:
  - Incadescent flashlight bulb and photocell
  - Red LEDs and visible-light-sensitive photo-transistors
  - IR emitters and detectors
- Where have you seen these?
  - Break beams and clever burglars in movies
  - In robotics they are mostly used for keeping track of shaft rotation

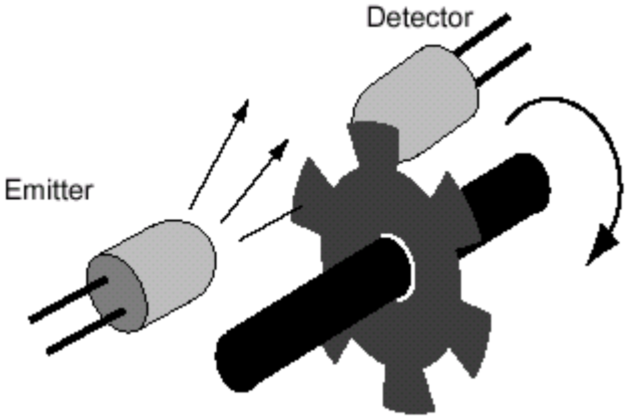




Shaft Encoding

- Shaft encoders
  - Measure the angular rotation of a shaft or an axle
- Provide position and velocity information about the shaft
- Speedometers: measure how fast the wheels are turning
- Odometers: measure the number of rotations of the wheels

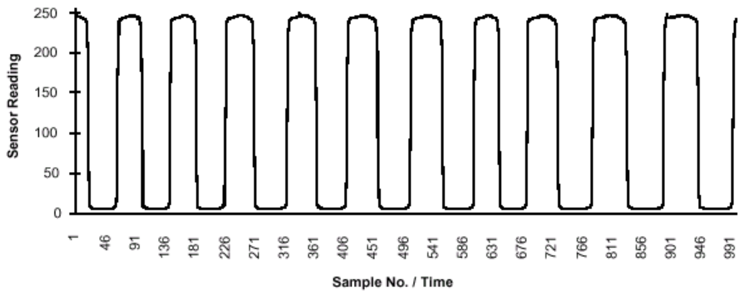
Measuring Rotation



- A perforated disk is mounted on the shaft
- An emitter–detector pair is placed on both sides of the disk
- As the shaft rotates, the holes in the disk interrupt the light beam
- These light pulses are counted thus monitoring the rotation of the shaft
- The more notches, the higher the resolution of the encoder
  - One notch, only complete rotations can be counted

General Encoder Properties

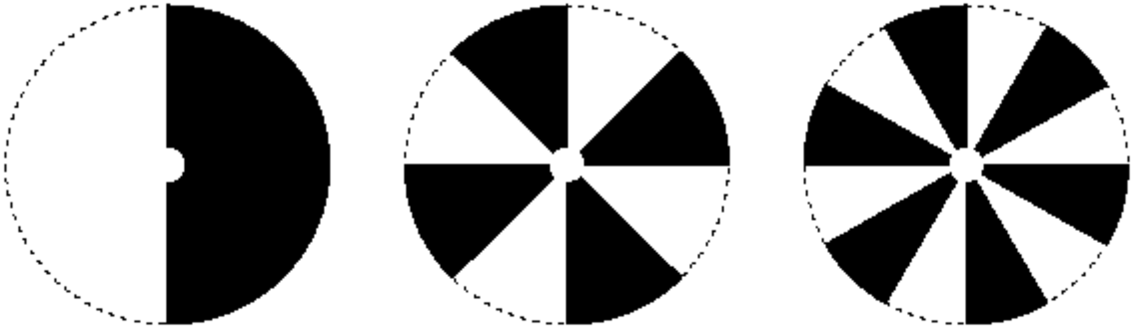
- Encoders are active sensors
- Produce and measure a wave function of light intensity



- The wave peaks are counted to compute the speed of the shaft
- Encoders measure rotational velocity and position

Color-Based Encoders

- Use a reflectance sensors to count the rotations
- Paint the disk wedges in alternating contrasting colors
- Black wedges absorb light, white reflect it and only reflections are counted

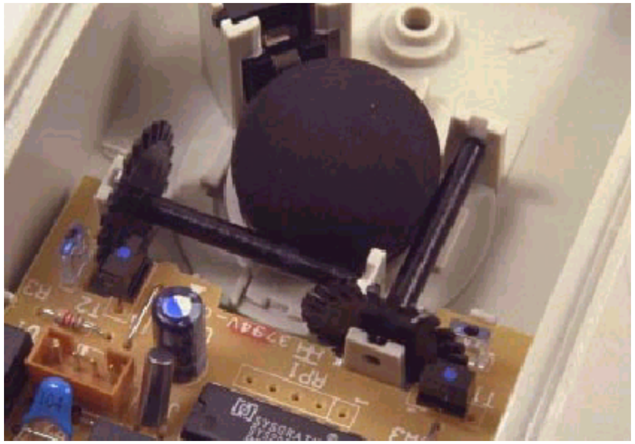


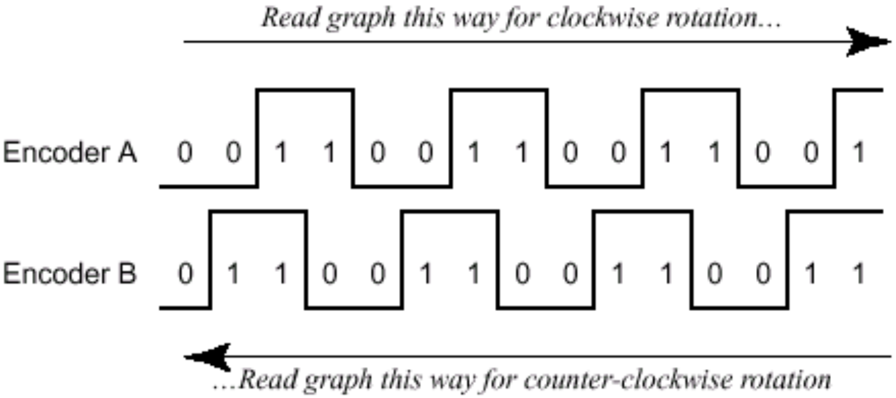
Uses of Encoders

- Velocity can be measured
  - at a driven (active) wheel
  - at a passive wheel (e.g., dragged behind a legged robot)
- By combining position and velocity information, the robot can:
  - move in a straight line
  - rotate by a fixed angle
- Can be difficult due to wheel and gear slippage and to backlash in geartrains

Quadrature Shaft Encoding

- How can we measure direction of rotation?
- Idea:
  - Use two encoders instead of one
  - Align sensors to be 90 degrees out of phase
  - Compare the outputs of both sensors at each time step with the previous time step
  - Only one sensor changes state (on/off) at each time step, based on the direction of the shaft rotation ⇒ this determines the direction of rotation
  - A counter is incremented in the encoder that was on





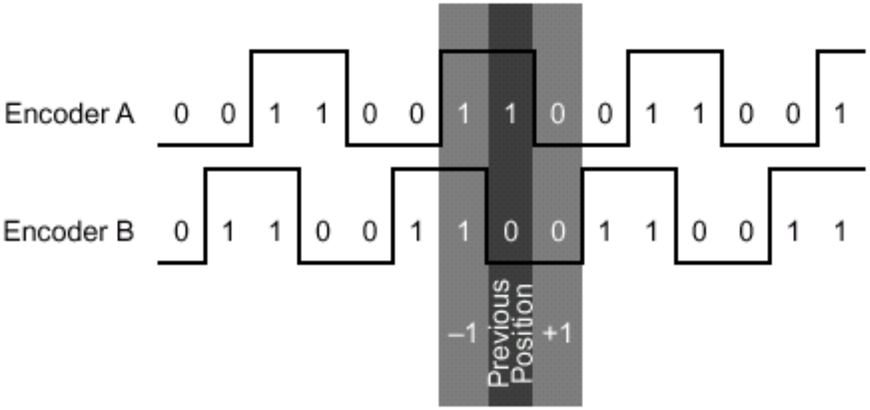
Which Direction is the Shaft Moving?

Encoder A = 1 and
Encoder B = 0

- If moving to position AB=00, the position count is incremented
- If moving to the position AB=11, the position count is decremented

- Previous state = current state ⇒ no change in position
- Single-bit change ⇒ incrementing / decrementing the count
- Double-bit change ⇒ illegal transition

Which Direction is the Shaft Moving?



Current State

Previous State

	00	01	10	11
00	0	+1	–1	×
01	–1	0	×	+1
10	+1	×	0	–1
11	×	–1	+1	0

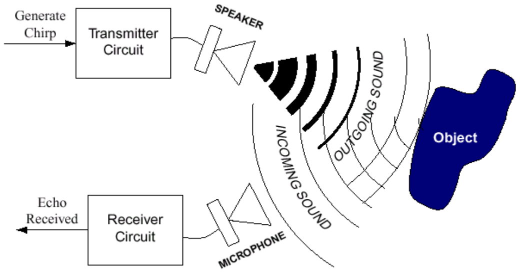
0 = no change
–1 = decrement count
+1 = increment count
× = illegal transition

"01" = encoder A is 0, encoder B is 1

Uses of QSE in Robotics

- Robot arms with complex joints
  - e.g., rotary/ball joints like knees or shoulders
- Cartesian robots, overhead cranes
  - The rotation of a long worm screw moves an arm/rack back and fort along an axis
- Copy machines, printers
- Elevators
- Motion of robot wheels
  - Dead-reckoning positioning

Ultrasonic Distance Sensing



- **Sonars:** so(und) na(vigation) r(anging)
- Based on the time-of-flight principle
- The **emitter** sends a “chirp” of sound
- If the sound encounters a barrier it reflects back to the sensor
- The reflection is detected by a **receiver** circuit, tuned to the frequency of the emitter
- **Distance** to objects can be computed by measuring the elapsed time between the chirp and the echo
- Sound travels about 0.89 milliseconds per foot

Sonar Sensors

- **Emitter** is a **membrane** that transforms mechanical energy into a "ping" (inaudible sound wave)
- The **receiver** is a **microphone** tuned to the frequency of the emitted sound
- Polaroid Ultrasound Sensor
  - Used in a camera to measure the distance from the camera to the subject for auto-focus system
  - Emits in a 30 degree sound cone
  - Has a range of 32 feet
  - Operates at 50 KHz

Echolocation

- **Echolocation** = finding location based on sonar
- Numerous animals use echolocation
- Bats use sound for:
  - finding pray, avoid obstacles, find mates, communication with other bats

Dolphins/Whales:

find small fish, swim through mazes

- Natural sensors are much more complex than artificial ones

Is It Possible?- Real Life Batman

http://www.youtube.com/watch?v=vpxEmD0gu0Q

Specular Reflection

- Sound does not reflect directly and come right back
- Specular reflection
  - The sound wave bounces off multiple sources before returning to the detector
- Smoothness
  - The smoother the surface the more likely is that the sound would bounce off
- Incident angle
  - The smaller the incident angle of the sound wave the higher the probability that the sound will bounce off

Improving Accuracy

- Use rough surfaces in lab environments
- Multiple sensors covering the same area
- Multiple readings over time to detect "discontinuities"
- Active sensing
- In spite of these problems sonars are used successfully in robotics applications
  - Navigation
  - Mapping

Laser Sensing

- High accuracy sensor
- Lasers use light time-of-flight
- Light is emitted in a beam (3mm) rather than a cone
- Provide higher resolution
- For small distances light travels faster than it can be measured ⇒ use phase-shift measurement
- SICK LMS200
  - 360 readings over an 180-degrees, 10Hz
- Disadvantages:
  - cost, weight, power, price
  - mostly 2D

Summary

- There are many types o sensors
  - Biggest difference is passive vs active
    - passive usually less energy consumption, but maybe to simple
  - sensors provide a measurement, it is still quite challenging to identify what does that mean of the state of the world.

THANK YOU