LECTURE 4 - 1

Common Sensing Techniques for Reactive Robots

Introduction to AI Robotics (Sec. 6.1 – 6.5)

Quote of the Week

"Just as some newborn race of superintelligent robots are about to consume all humanity, our dear old species will likely be saved by a Windows crash. The poor robots will linger pathetically, begging us to reboot them, even though they'll know it would do no good."

-Anonymous

ANNOUNCEMENTS

- Lab 4 - Line Following (PI Control) is due on Thursday, 4/1/10
- The lab memo is due on Angel by midnight on Thursday, 4/1/10
- Quiz 7 on Sec. 6.1 – 6.5, Lecture 4-1 on Tuesday, 3/30/10

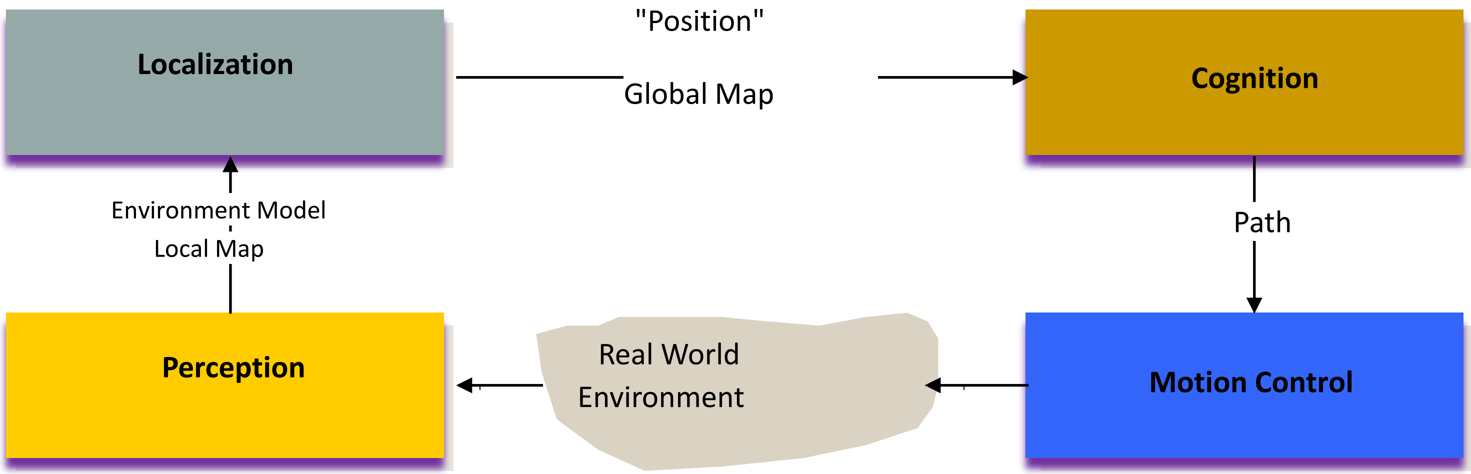
OBJECTIVES

Upon completion of this lecture the student should be able to:

- Define the difference between active and passive sensors
- Define the following terms in one or two sentences: *proprioception, extereoception, exproprioception, proximity sensor, logical sensor, false positive, false negative*
- List the metrics for rating sensors
- Describe the problems of *specular reflection*, *cross talk*, and *foreshortening* with an ultrasonic transducers
- Describe the types of behavioral sensor fusion and be able to apply to a real world problem
- Write perceptual schemas from any logical equivalent range sensor to produce a polar plot for obstacle avoidance behavior

PERCEPTION

One of the most important tasks of an autonomous mobile robot is ***perception***. Perception is used for the robot to acquire knowledge from it's environment. Perception involves taking measurements using various sensors and extracting meaningful information.



PERCEPTION

- *Perception* in a reactive robot system has two roles:
  - Release a behavior
  - Guide the actions of the behavior
- All sensing is behavior-specific
- The *sensor* or *transducer* is a device that measures the attributes of the world
- A *transducer* is the mechanism of a sensor that transform the energy associated with what is measured into another form of energy. (i.e. sound, light, pressure, temperature to an analog or digital form)

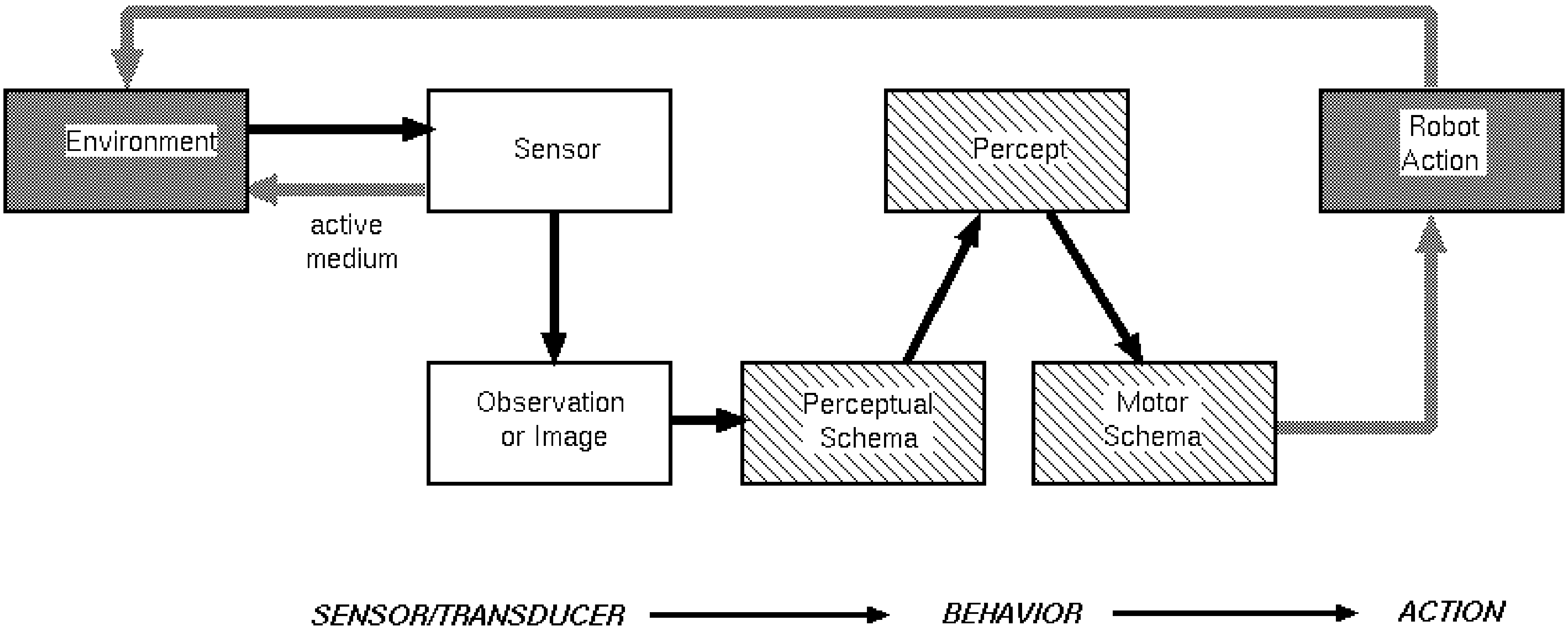
SENSING

- A robot's intelligence depends on
  - The quality and quantity of its sensors
  - The ability to process and speed of processing sensory input
- Sensing allows a robot to know its ***state*** or description of itself at any point in time
- A robot's state may be ***visible, partially hidden***, or ***hidden***
- A state may be ***discrete*** or ***continuous***
- A state space consists of all of the possible states a system can be in

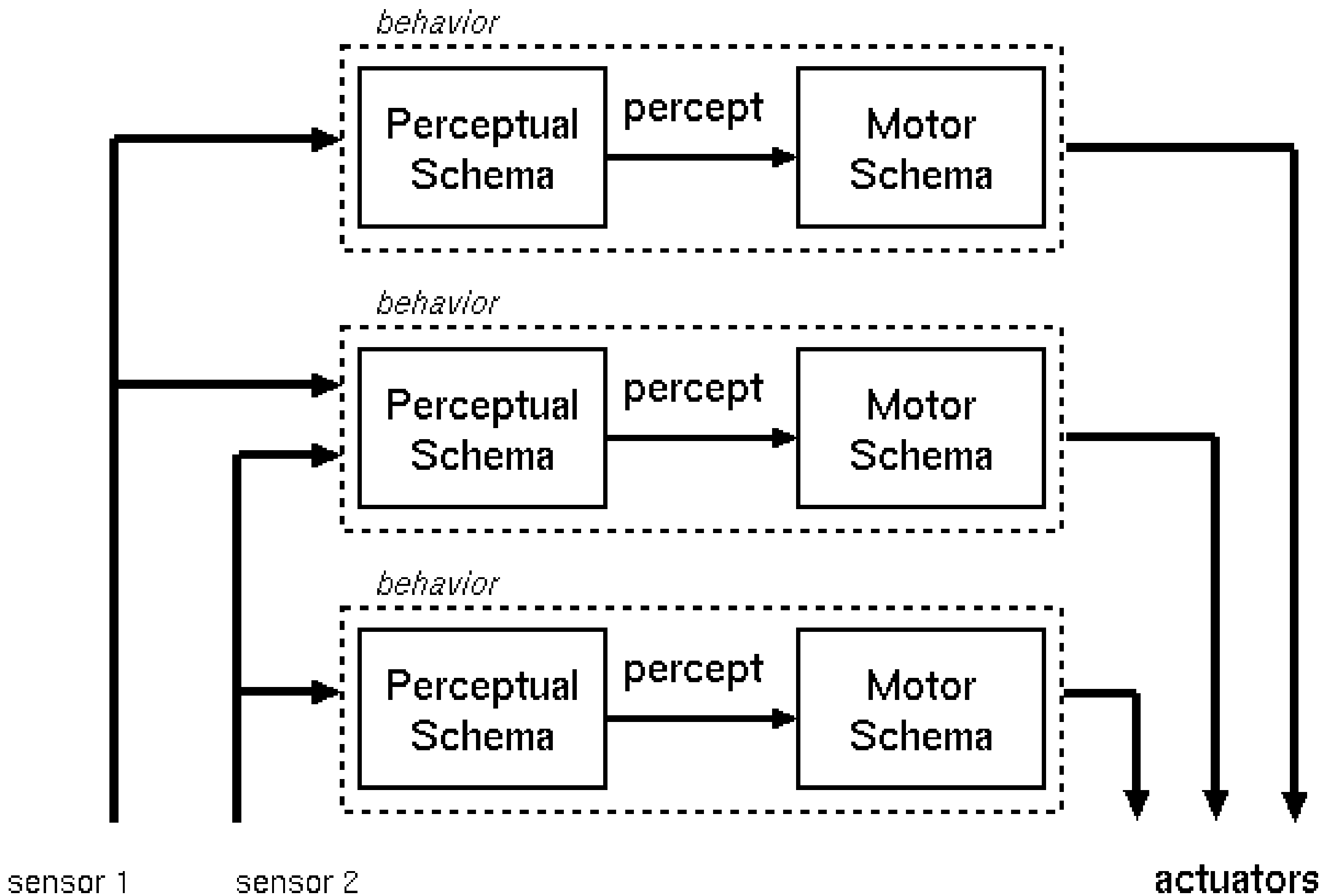
SENSING CONT.

- ***External state*** is the robot’s perception of the world
- ***Internal state*** is the robot’s perception of itself
- ***Representation*** or ***internal model*** is created when a robot uses its internal state to remember information about the world.
- A robot’s ***sensor space*** or ***perceptual space*** is the space of all possible sensory readings based upon all of the robot’s sensors

A MODEL OF SENSING

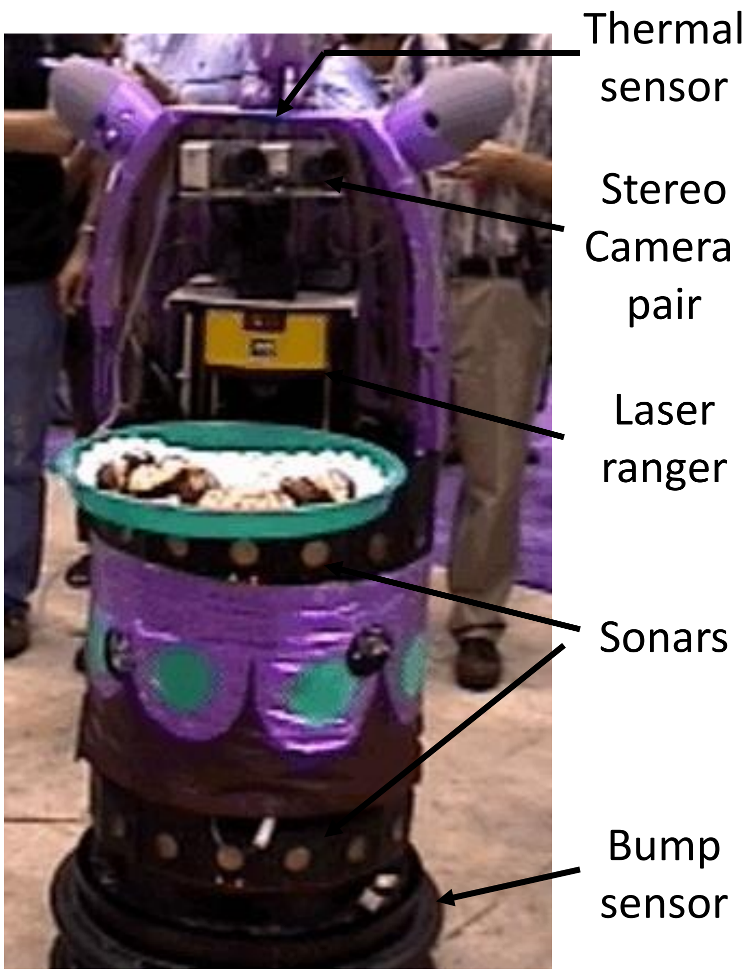


SENSING IN REACTIVE PARADIGM



ACTIVE VS PASSIVE SENSING

- Active Sensors
  - Emits some form of energy and then measures the return to understand the environment (sonar, laser)
- Passive Sensors
  - Receives energy already in the environment (camera)



SIMPLE VS. COMPLEX SENSORS

- Simple sensors do not require a great deal of processing or computation but the information they provide is simple or limited (i.e. light levels, presence or absence of objects, distance to objects)
- ***Passive sensors*** can be simple or complex
  - the camera is a complex passive sensor
- ***Active sensors*** are not necessarily complex
  - break beam sensors are simple active sensors
- Whether a sensor is simple or complex is determined by the amount of ***processing*** its data require
- Whether a sensor is active or passive is determined by the ***mechanism*** used to extract data

SENSORS

- A robot's intelligence is typically measured by the diversity of its sensor suite.
- ***Proprioceptive Sensors*** perceive elements in the robot's internal state. For example, encoders on motors for distance or velocity or battery voltage.
- ***Exteroceptive Sensors*** perceive elements in the state of the external world around the robot. For example, infrared sensors for distance, temperature or light intensity.
- Proprioceptive and Exteroceptive sensors combine to make the robot's ***perceptual system***

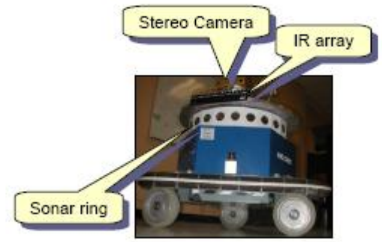
SENSOR DIVERSITY

- Robots have different types of sensors to allow:
  - Flexibility in type of data (direction, distance, light, sound, temperature)
  - Sensor fusion to obtain a more accurate representation of the world
- Multiple Sensors
  - Speed up the rate of environment readings
  - Provide redundancy and fault tolerance
  - Save power

SIGNAL VERSUS STATE

- Sensors do not provide state information but rather data or physical quantities. These measurements must be processed in order to be useful
- Because sensors are prone to error, there are several sensors that measure the same quantity and can be used for ***sensor redundancy***
- ***Sensor fusion*** is when multiple sensors are used to create some knowledge or get better information about the robot's internal and/or external state.

SENSOR FUSION



- To account for inaccuracies, multiple sensors are often combined (or fused)
- *Sensor Fusion* combines sensor readings from
  - The same sensor
    - Taken as an average, minimum or maximum over some small time interval (infrared sensor)
  - Multiple similar sensors
    - Individual sensors read from different directions (sonar ring)
  - Different kinds of sensors
    - Combine sonar, infrared, and vision measurements

BEHAVIORAL SENSOR FUSION

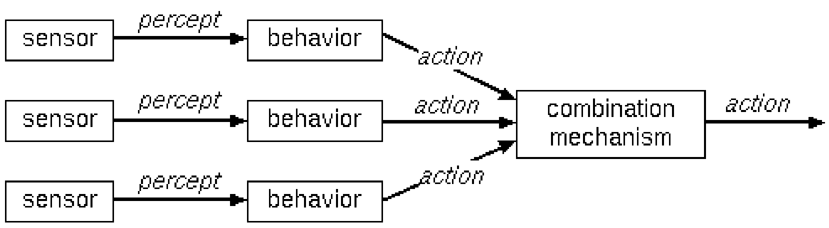
- Three basic combinations of sensors
  - Redundant (or competing)
  - Complementary
  - Coordinated
- When a sensor leads to robot to believe a percept is present but it is not is called a *false positive*
- When a robot misses a percept it is a *false negative*
- *Redundant sensors* return the same percept (physical or logical)
- Complementary sensors return disjoint types of information about a percept
- Coordinated sensors use a sequence of sensors for providing focus of attention

UNCERTAINTY

- ***Uncertainty*** refers to the robot's inability to be certain about the state of itself or the environment.
- Some of the sources of uncertainty are:
  - Sensor noise and errors
  - Sensor limitations
  - Effector and actuator noise and errors
  - Hidden and partially observable state
  - Lack or prior knowledge about the environment
  - Dynamic and changing environment

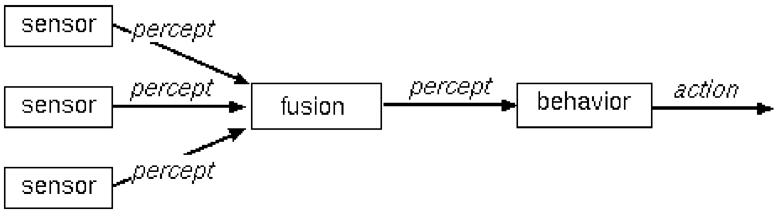
BEHAVIORAL SENSOR FUSION:

Sensor fission
Emergent behavior (competing)



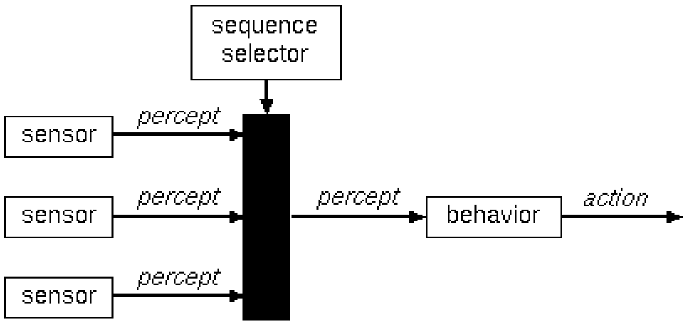
a.

Action-oriented sensor fusion (complementary)



b.

Sensor fashion (coordinated)



c.

SENSOR QUESTIONS

- Given a sensory reading, what should I do?
  - Easy to answer with a simple sensor, i.e. if the bump sensor is triggered, the robot should stop
  - Hard to answer with a complex sensor, i.e. if the camera image contains a wall, the robot should ?
- Given a sensory reading, what was the world like when the reading was taken?
  - May not be easy to answer with simple or complex sensors
  - Simple sensors do not prove enough information for reconstruction of the world. i.e. if the bump sensor is triggered, what did it hit?
  - Complex sensors provide this information but require a great deal more processing

HOW DO YOU RATE SENSORS?

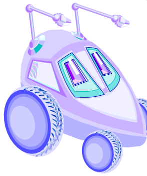
- **Field of view, range**: does it cover the “right” area
- **Accuracy & repeatability**: how well does it work?
- **Responsiveness in target domain**: how well does it work for *this* domain?
- **Power consumption**: may suck the batteries dry too fast
- Reliability: can be a bit flakey, vulnerable
- **Size**: always a concern!
- **Computational Complexity**: can you process it fast enough?
- **Interpretation Reliability**: do you believe what it’s saying?

PROXIMITY SENSORS

- Detect objects within a specific range from the robot
- Provide a ***binary*** signal according to some threshold
- Tactile sensors are an example of proximity sensors
- Non-tactile sensors that detect the absence or presence of a light reflect are ***encoders***
- Non-tactile sensors are usually active
- Range sensors can be configured as proximity sensors by setting a threshold

ACTIVE RANGING

- *Active ranging sensors* are the most popular sensors in mobile robotics
- *Active ranging sensors* are used for
  - Obstacle detection
  - Obstacle avoidance
  - Localization
  - Environment modeling
- Ultrasonic sensors and laser range sensors use the propagation speed of sound or electromagnetic waves.

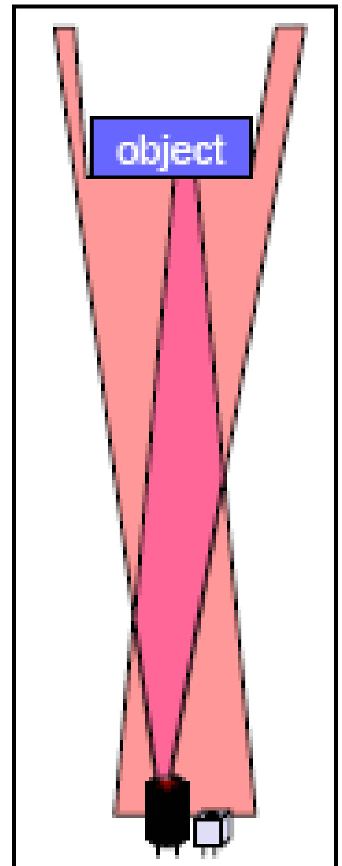


COMMON RANGE SENSORS

- Commonly used range sensors in robotics include:
  - Tactile and proximity sensors
  - Ultrasonic sensors
  - Infrared range sensors
  - Laser range finders
  - Vision systems
- Each varies in complexity, size, weight, expense, accuracy, etc..
- The ***detection range*** is defined as the maximum distance that the sensor can read reliably

INFRARED RANGE SENSORS

- Emit light from Infrared LED
- Light is reflected from object
- Receiver measures strength of light returned
- Range depends on object properties
  - Shiny objects (metal) are difficult to detect
  - Cannot detect glass
  - White/black surfaces report different ranges

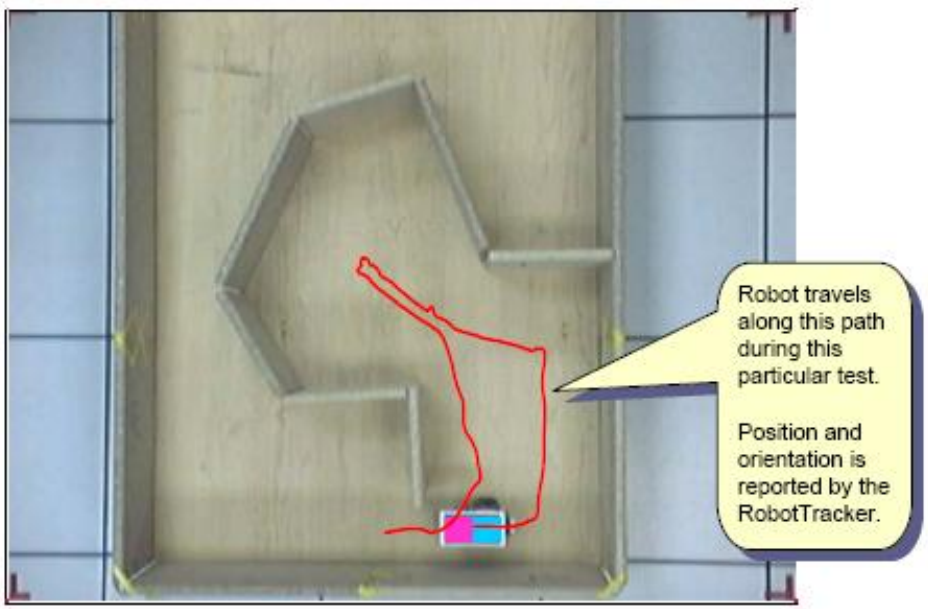


TIME OF FLIGHT

- ***time of flight*** is used to determine distance to objects
- The measured pulses typically come form ultrasonic, RF and optical energy sources.
  - **d = c * t**
  - d = round-trip distance
  - c = speed of wave propagation
  - t = time of flight

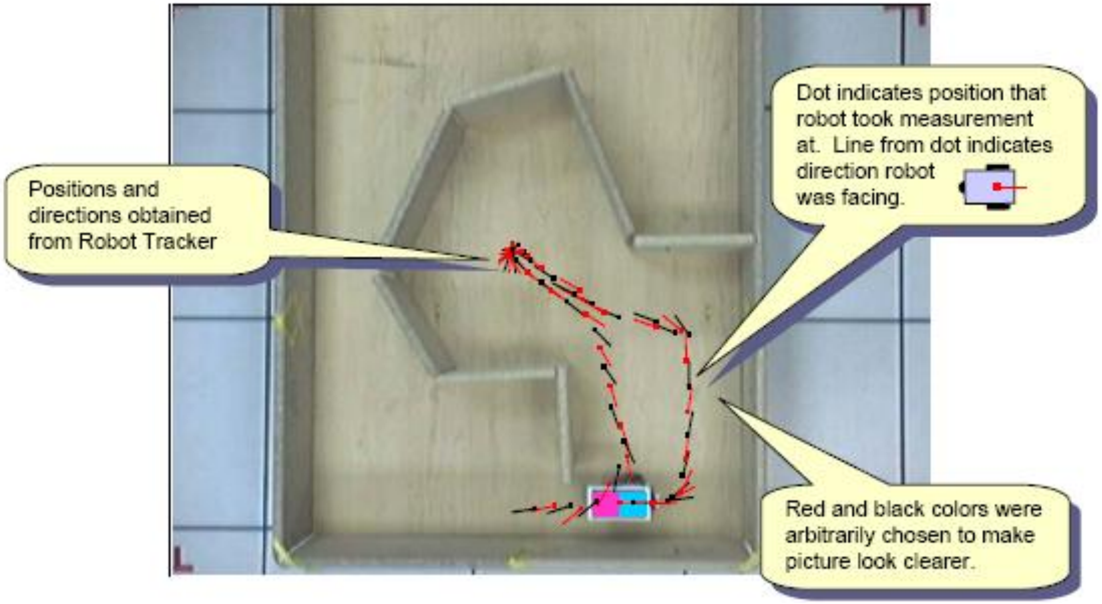
INFRARED SENSORS: MAPPING EXAMPLE

- Use the IR sensor to compute the range to obstacles along a long a path in the following environment



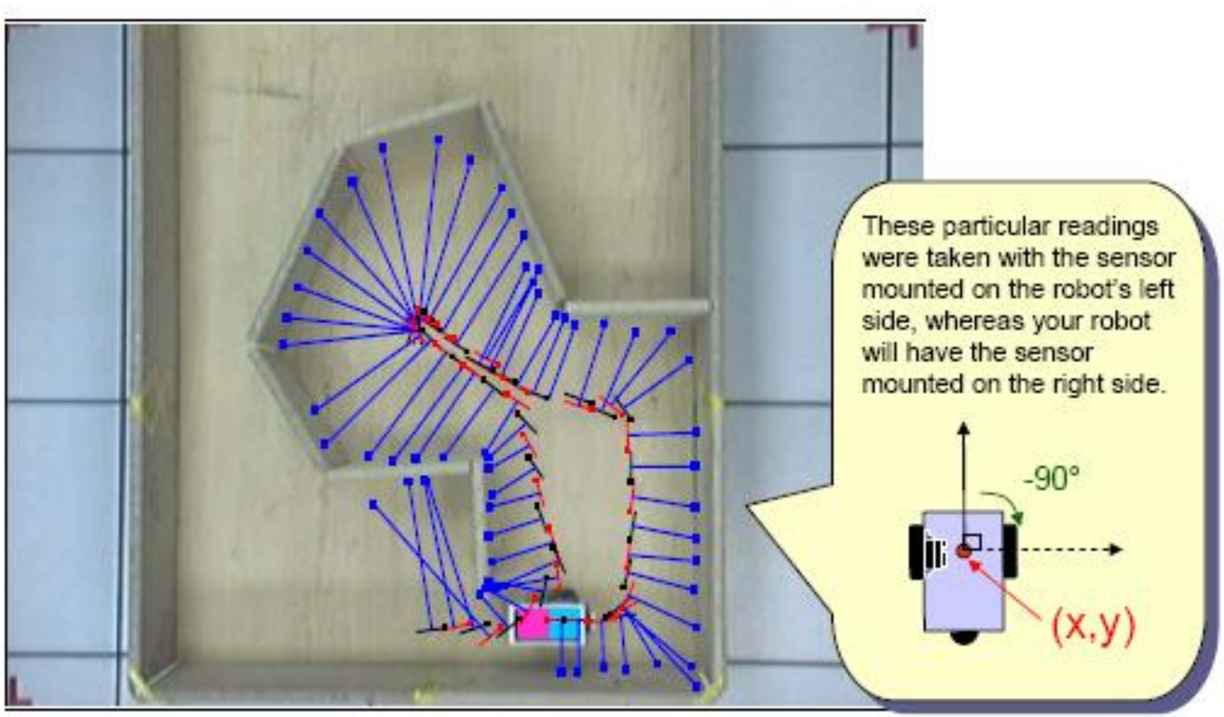
INFRARED SENSORS: MAPPING EXAMPLE

Take measurements along the path at particular locations



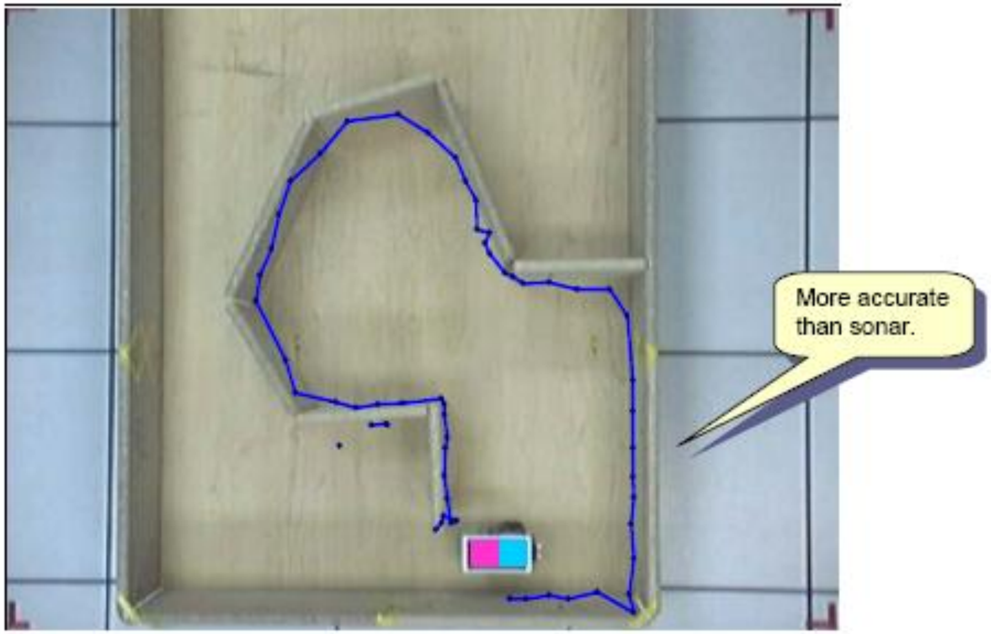
INFRARED SENSORS: MAPPING EXAMPLE

Blue lines show readings to obstacles form the robot's center position (x, y)



INFRARED SENSORS: MAPPING EXAMPLE

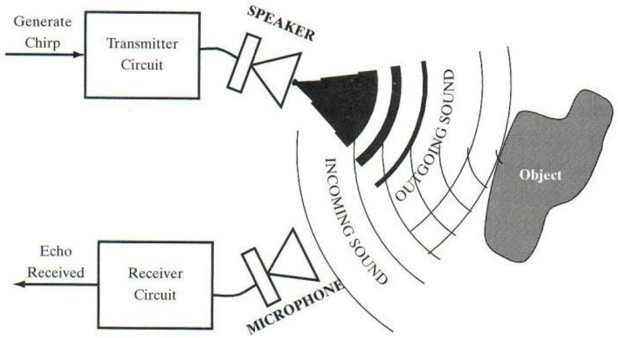
- The resulting map has reasonable accuracy
- The map can be refined by taking additional readings



IR SENSORS:
ADVANTAGES AND DISADVANTAGES

- Advantages
  - Reliable with good precision
  - Small beam angle
  - inexpensive
- Disadvantages
  - Sensitive to smoothness
  - Sensitive to angle to obstacles
  - Short range
  - Prone to interference from ambient light
  - Cannot detect glass, mirror, shiny surfaces

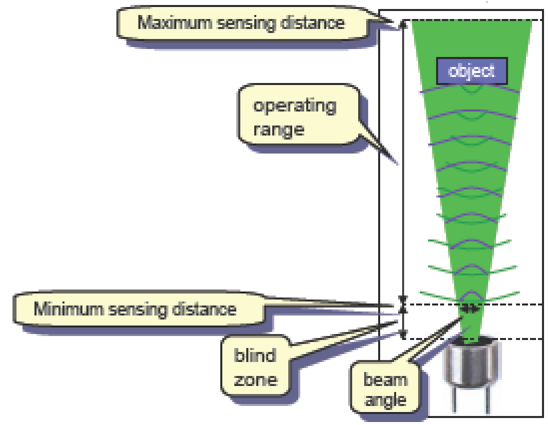
SONAR

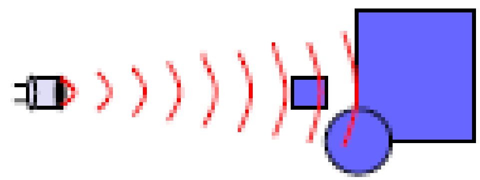


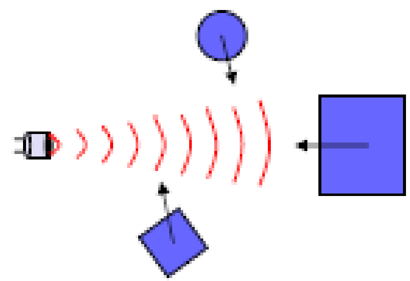
- *Ultrasound (sonar)* refers to the range of frequencies of sound that are beyond human hearing
- The process of finding your location based upon sonar is *echolocation*
- Sonar are active sensors that emit a chirp or ping and use time of flight to determine distance
- The transducer on a sonar emits the chirp/ping and receives the sound (echo) that comes back.
- Mechanical energy is converted into sound as the membrane on the transducer flexes to produce a ping

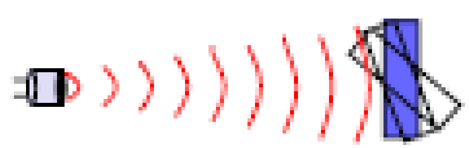
SONAR: RELIABILITY

- *Blind zone* is when an echo arrives before the transducer is ready to receive and objects are not detected reliably
- Sensor readings vary based upon:
  - Distance to object(s)
  - Angle that object makes with respect to sensor axis
  - Direction that objects enter sensing range



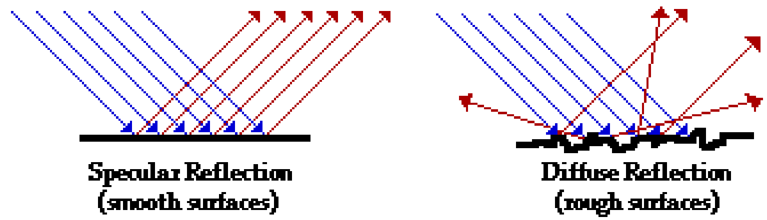


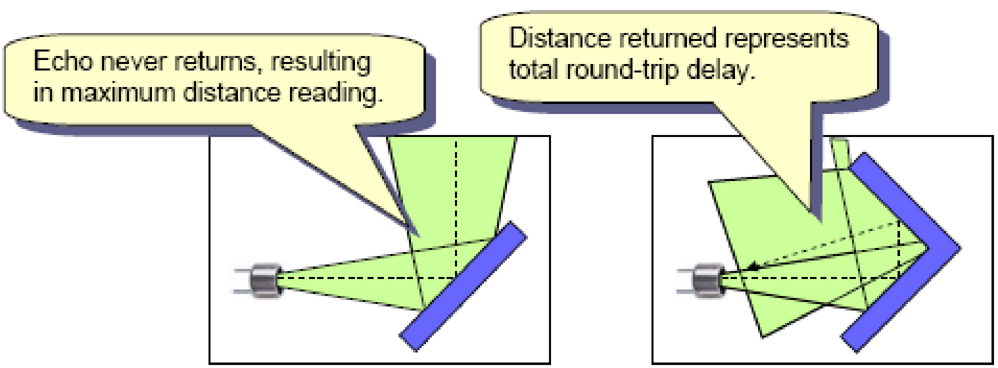




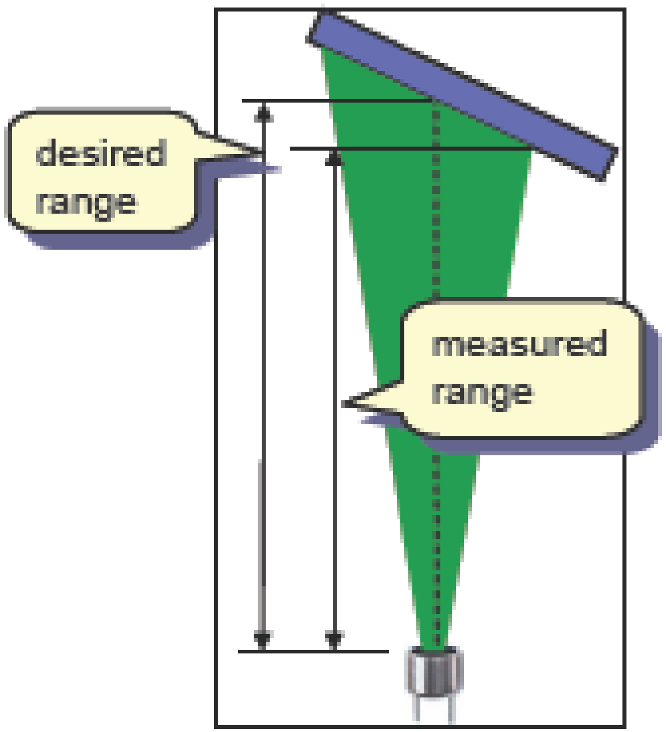
SONAR:
SPECULAR REFLECTION

- Specular reflection can cause reflected sound to
  - Never return to the transducer
  - Return to the transducer too late
- The results is that the distance measurement is too large and inaccurate





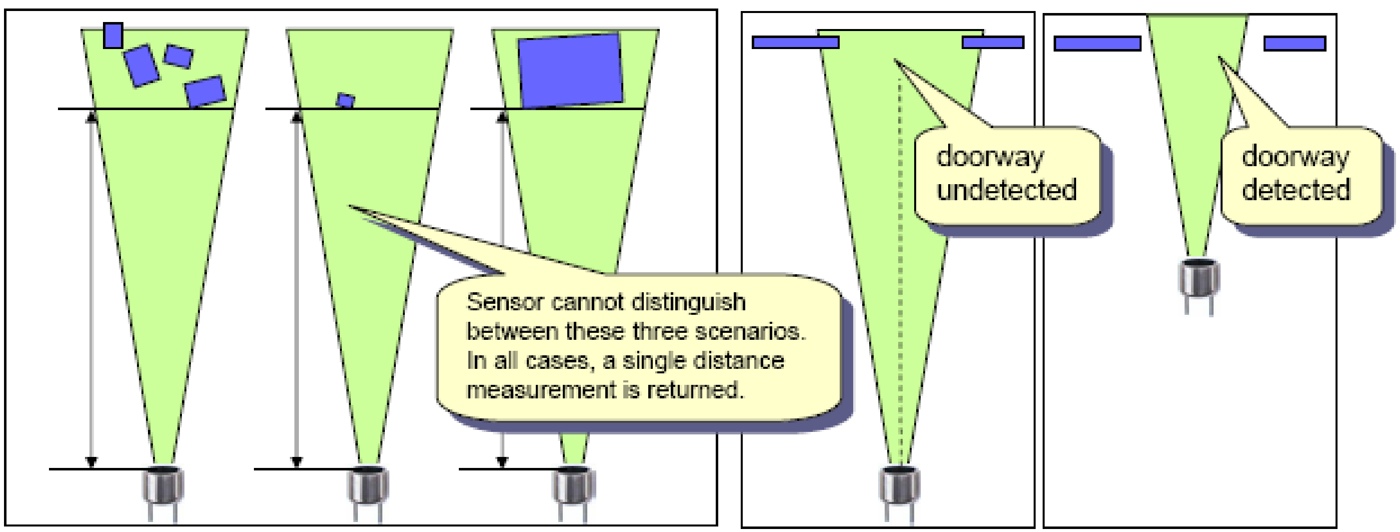
SONAR: SENSITIVITY



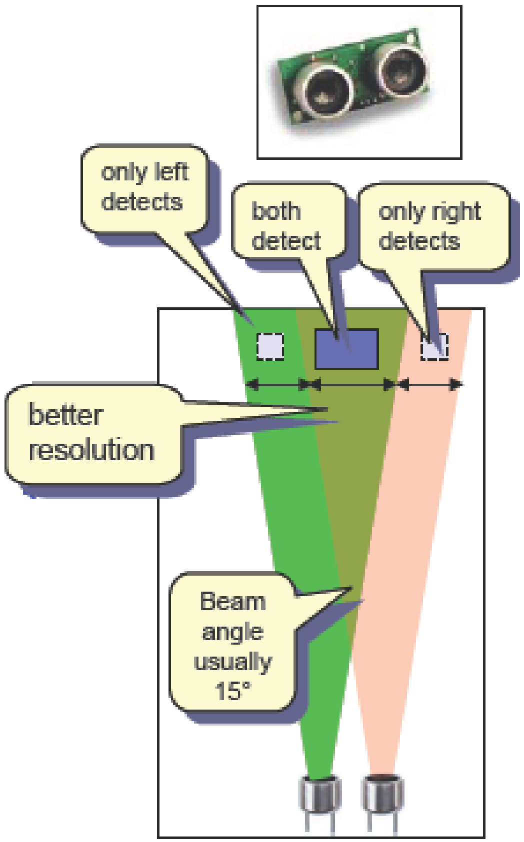
- *Sensitivity* to obstacle angle can result in improper range readings
- When the beam angle of incidence falls below a certain critical angle *specular reflection* errors occur

SONAR: RESOLUTION

- Distance and angular resolution decreases as objects become further from the sensor
  - Multiple close objects cannot be distinguished
  - Gaps such as doorways cannot be detected



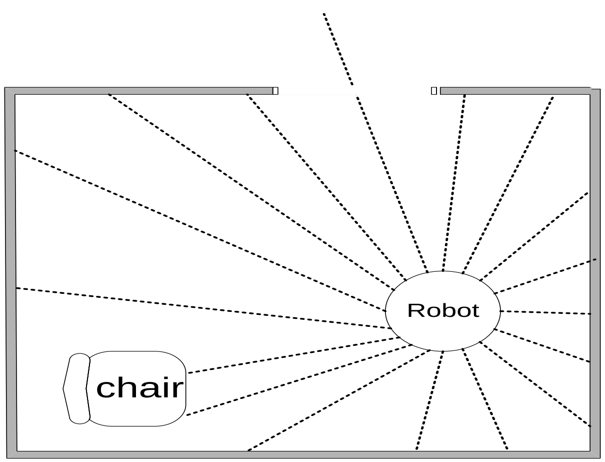
ULTRASONIC RANGE SENSORS: REDUNDANCY

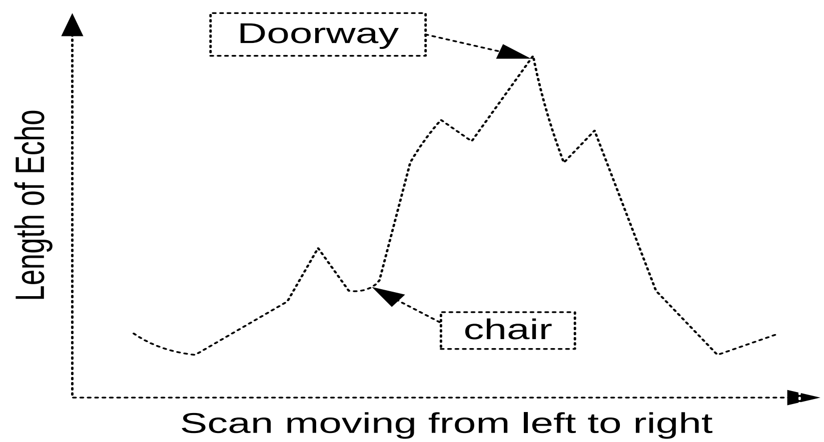


- To increase beam width (*resolution*), two sensors are used together
- Detection in either or both sensors allows for increased resolution

ULTRASONIC RANGE SENSORS: APPLICATIONS

- Distance Measurement
- *Mapping*: Rotating proximity scans (maps the proximity of objects surrounding the robot)
  - Scanning at an angle of 15º apart can achieve best results

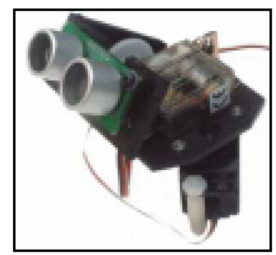




ULTRASONIC RANGE SENSORS: MAPPING

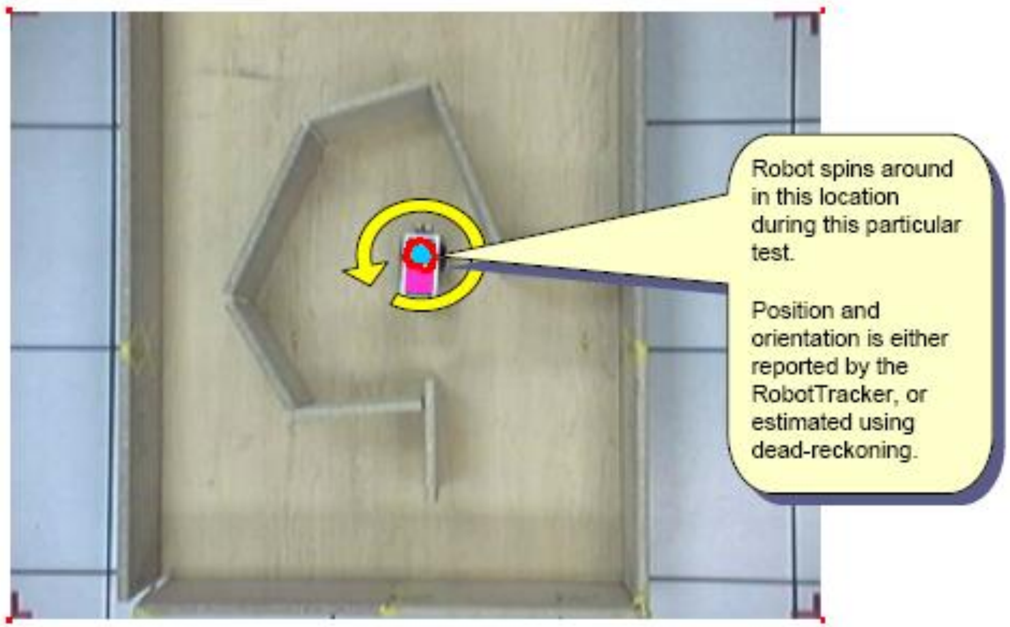
- To perform mapping take multiple readings:
    - Rotate the sensors
    - Rotate the robot chassis
    - Use multiple sensors at fixed positions on chassis





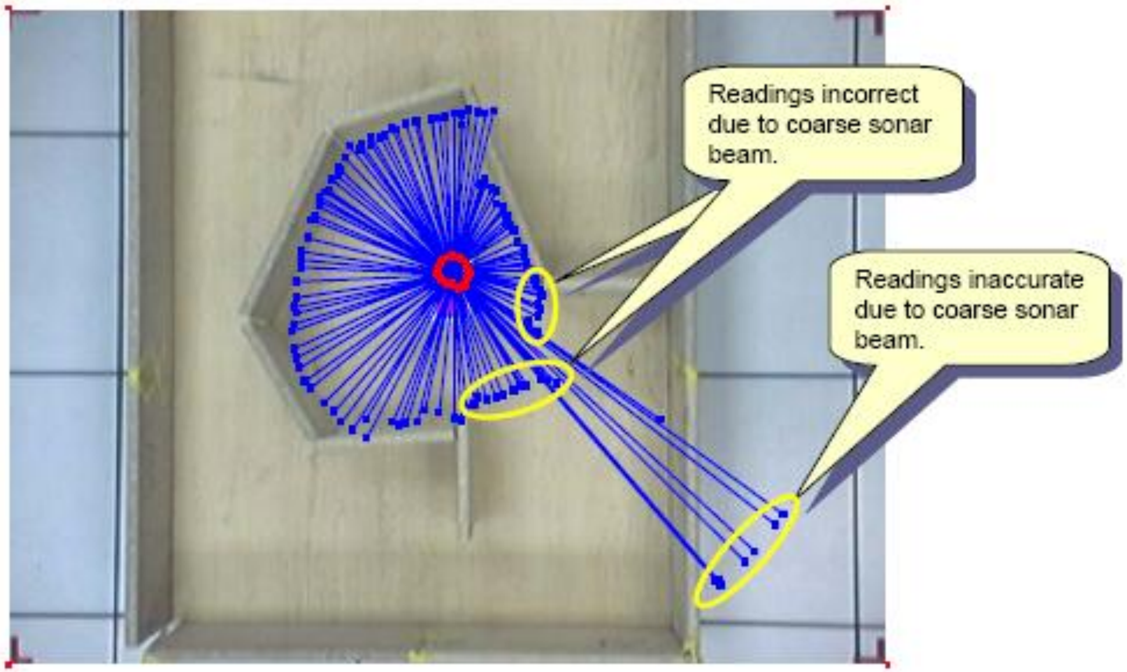
ULTRASONIC RANGE SENSORS: MAPPING EXAMPLE

Use sonar mounted to the front of a robot to compute the ranges to obstacles from a location in the environment



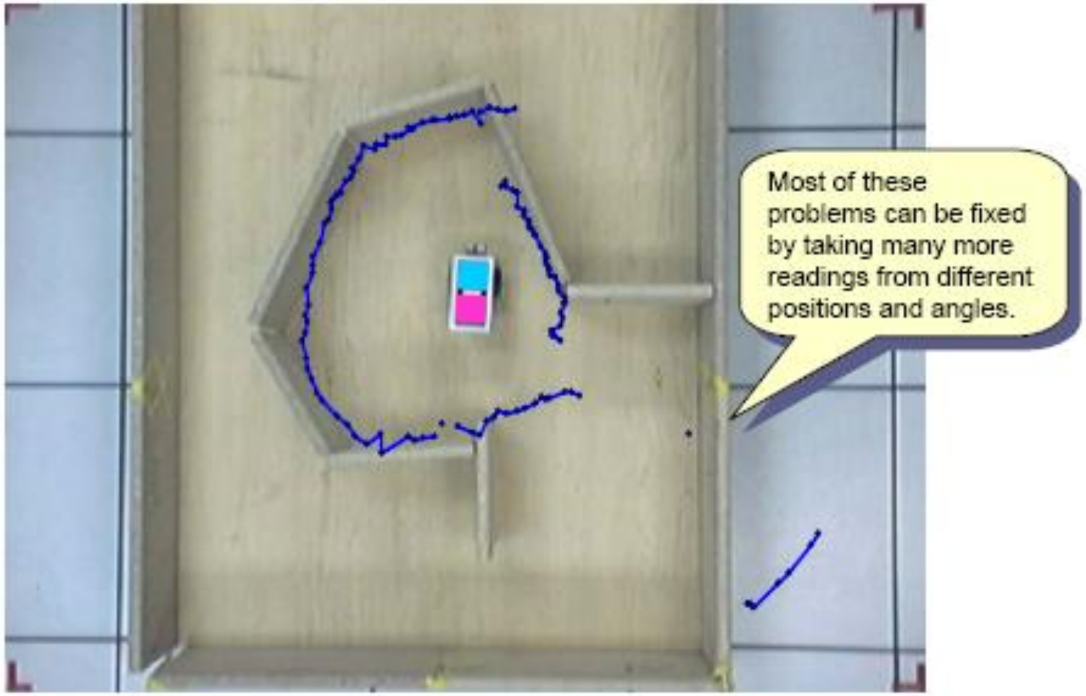
ULTRASONIC RANGE SENSORS: MAPPING EXAMPLE

Blue lines show sonar readings detected from the robot's position (x, y) to the obstacle position (x_o, y_o)



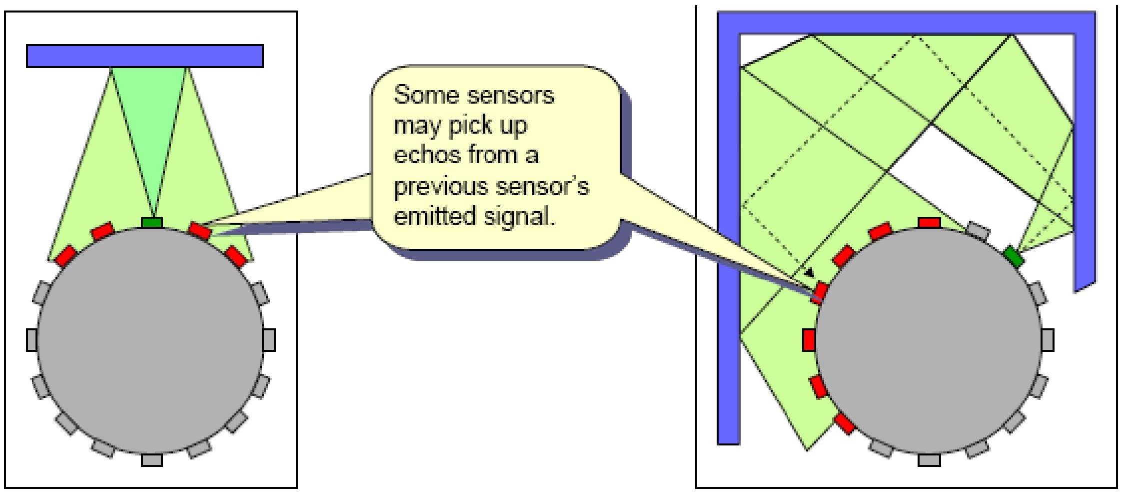
ULTRASONIC RANGE SENSORS: MAPPING EXAMPLE

The sonar data produces a 'rough' outline of the environment with some inaccurate readings

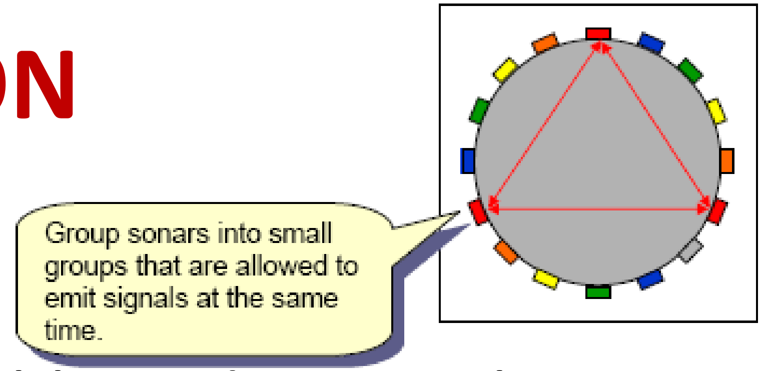


ULTRASONIC RANGE SENSORS: CROSSTALK

- Using multiple fixed sensors can lead to *crosstalk*
- *Crosstalk* is interference in which echoes emitted from one sensor are detected by others

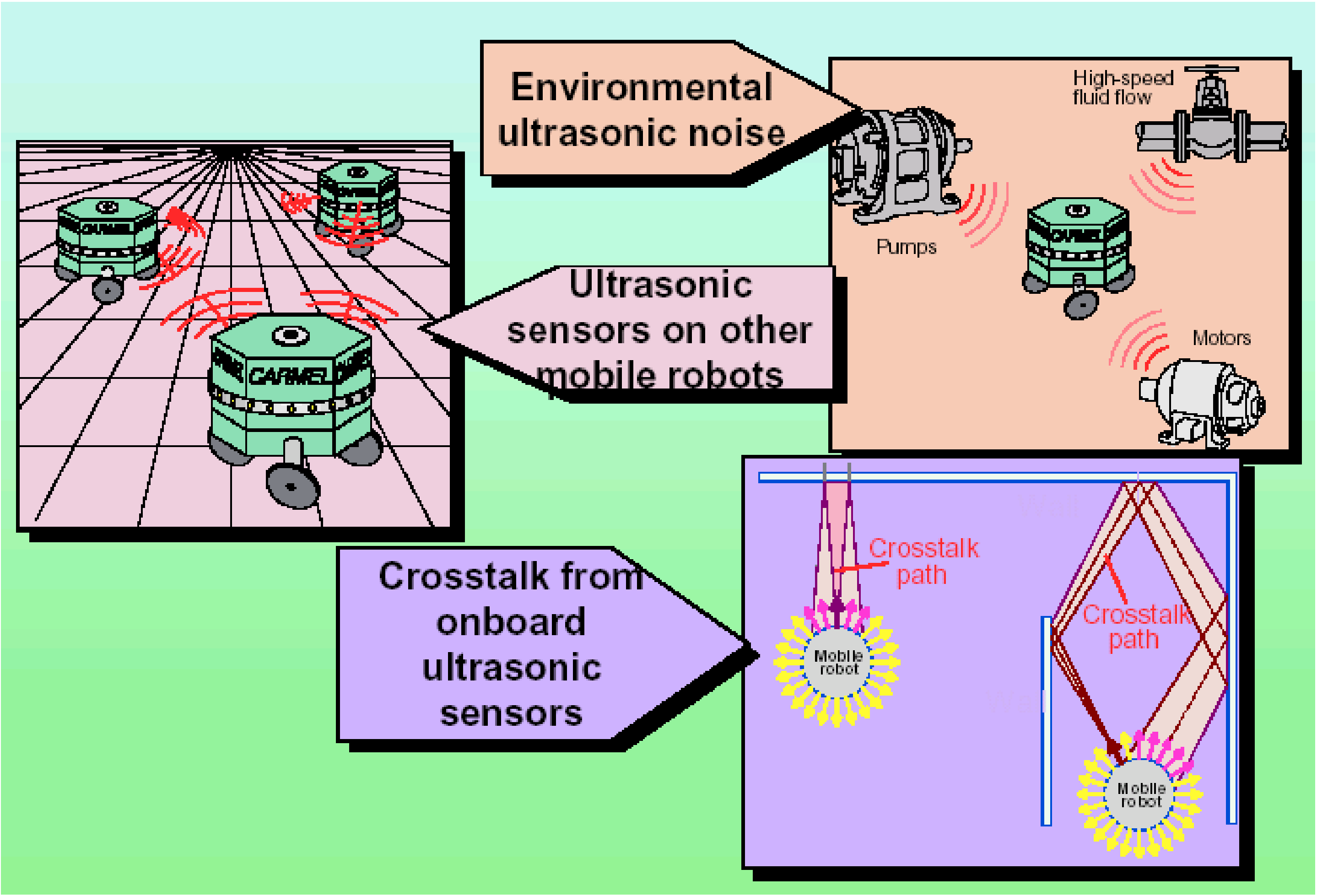


ULTRASONIC RANGE SENSORS: CROSSTALK SOLUTION



- Crosstalk signals are impossible to detect unless signals are unique (coded)
- Crosstalk can be reduced by carefully timing the emitting of signals
  - Emit from one and wait for a time interval
  - Emit from a select few that may not have interference
- Emit adjacent sensors at different frequencies

ULTRASONIC RANGE SENSORS: NOISE ISSUES



ULTRASONIC RANGE SENSORS: ADVANTAGES AND DISADVANTAGES

- Advantages
  - Reliable with good precision
  - Not as prone to outside interference
  - Good maximum range
  - Inexpensive
- Disadvantages
  - Sensitive to smoothness
  - Sensitive to angle to obstacles *(specular reflection)*
  - Poor resolution
  - Prone to self-interference from echoes
  - Cannot detect obstacles too close
  - Soft surfaces absorb sound energy
  - Bandwidth