MCE 412 - Autonomous Robotics

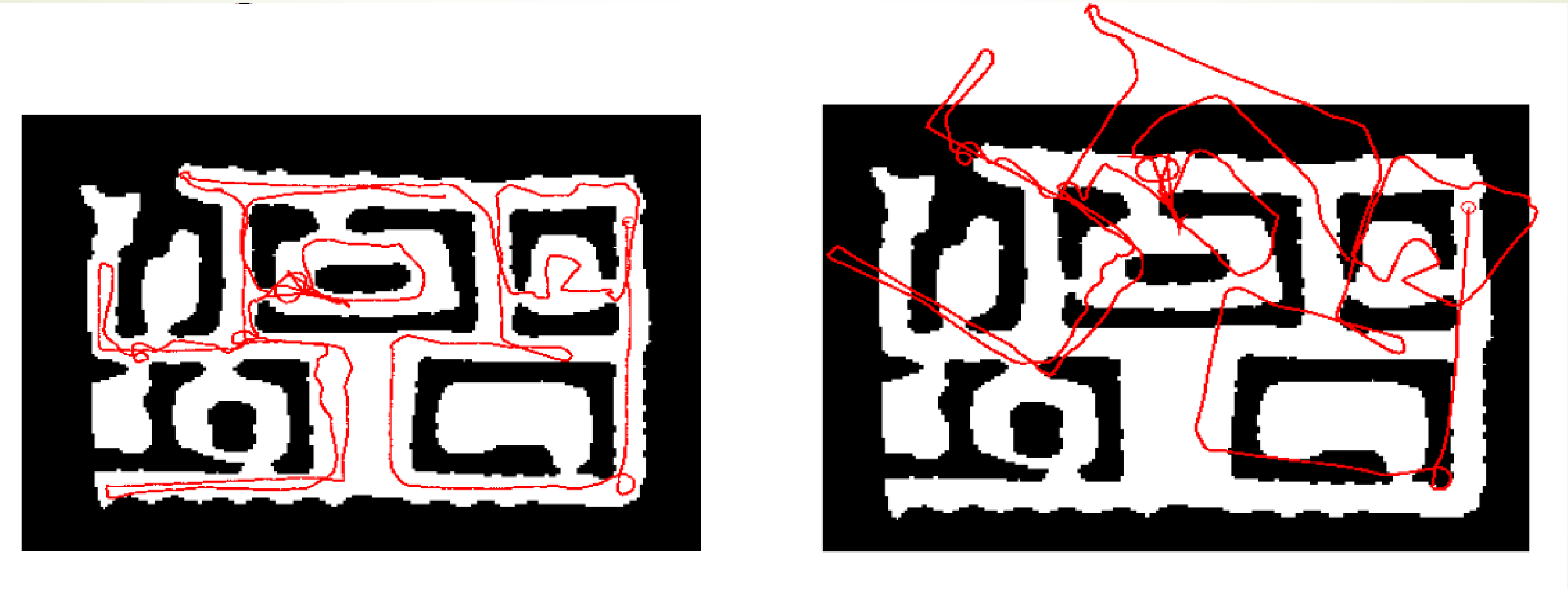
Sensors

Introduction

- Sensing is a critical component of the fundamental tasks of pose estimation, pose maintenance and map construction.
- Two different classes of sensors have emerged for mobile robots:
  - Viusal sensors which use light reflected from objects in the environment
  - Non-visual sensors which use various audio, inertial and other modalities

Dead Reckoning and Odometry:

- Estimating the motion based on the issued controls/Wheel encoder readings
- Integrated over time



Non-visual Sensors and Algorithms

Basic Concepts

- Internal State Sensors provide feedback on the internal parameters of a robotic system, i.e., the wheel position, the battery level…
- External State Sensors deal with the observation of aspects of the World outside the robot itself, i.e., humidity, the color of objects…
- Active sensors are those that make observations by emitting energy into the environment or by modifying the environment,i.e., touch or shout and listen for the echo.
- Passive sensors are those that passively receive energy to make their observations, i.e., human vision and olfaction (sense of smell).

IMPORTANT!

- Real sensors are noisy
- Real sensors return an incomplete description of the environment
- Real sensors cannot usually be modelled completely

!!! Underestimating the real properties of sensors and environmental complexity has led to the demise of many otherwise-promising projects in computer vision and robotics.

Sensor Technologies are classified based on the type of data returned

- Range sensors: distance
- Absolute position sensors
- Environmental sensors: temperature
- Inertial sensors: acceleration

Some more criteria

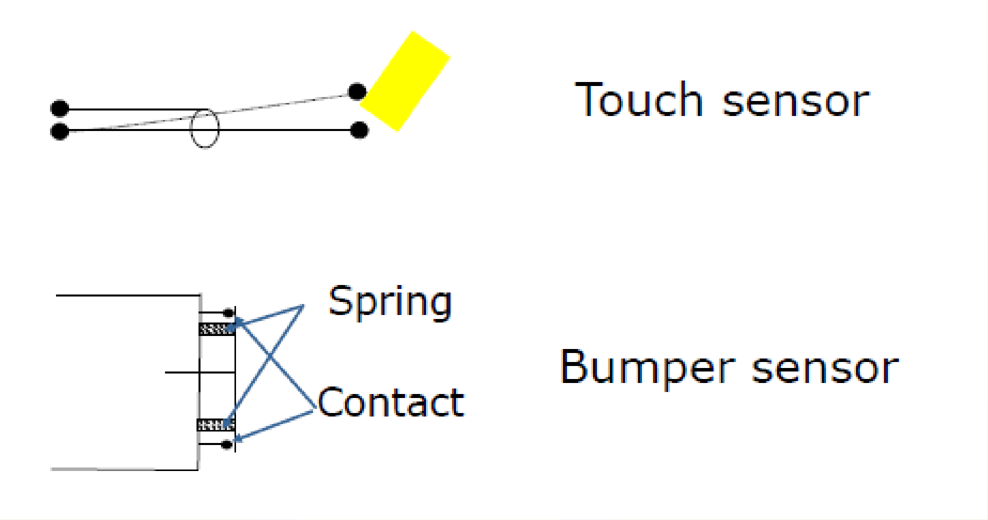
- Speed of operation
- Cost
- Error rate
- Robustness
- Computational requirements
- Power, weight and size requirements

- The relationship is modelled between the physical properties of interest in the environment e and the sensor reading r using the sensor model $r = f(e)$.
- The sensor model should include a model for both noise internal to the sensor and noise due to other sources.
- The problem of recovering the environment from the sensor data can be described as an **inverse problem**: to recover the arguments to a function, given the output of the function.
- ill-posed problems are problems with
  - a solution that is undefined
  - a solution that is not uniquely defined.
  - a solution that is not stable.

One approach to overcoming instability and other attributes of ill-posed problems is to apply techniques to overconstrain the system and to use an approach such as least-squares to make the measurement more accurate.

Contact Sensors: Bumpers

- Tactile sensors are those used to create a ‘sense of touch’.
- Touch sensors are commonly used in the bumpers of robotic vehicles.
- The simplest such devices are microswitches that report a binary value: open or closed
- More sophisticated approaches return a signal over a wide range of values in proportional to the force applied to them.



Inertial Sensors

- Inertial sensors measure derivates of the robot's position variables.
- Inertial sensor is commonly used to refer to accelerometers and gyroscopes, which measure the second derivatives of position, that is, the acceleration and angular acceleration of the vehicle.

Accelerometers:

- Accelerometers are essentially spring-mounted masses whose displacement under acceleration can be measured.
- Each accelerometer measures acceleration along a single direction.

$$a = \frac{kx^2}{m}$$

Gyroscopes:

- Gyroscopes measure angular acceleration by exploiting basic Newton mechanics.
- Mechanical gyroscope is a rapidly spinning mass suspended in a gimbal
- The gradual loss of accuracy due to error accumulation is referred to as **drift**.

An **inclinometer** is a device that measure the orientation of the gravity vector
A compass measures orientation with respect to Earth's magnetic field.

Infrared Sensors

- Near-infrared (IR) proximity detectors are fast and inexpensive proximity sensors.
- The basic concept is to emit an infrared pulse and detect the reflected signal.
- The distance to the target is estimated using the strength of the recovered signal and assumptions concerning the reflectivity of surfaces in the environment.
- Simple non-encoded signals are susceptible to interference (e.g., from sunlight)
- Even a more complex signal can be washed out if the ambient illumination is strong.

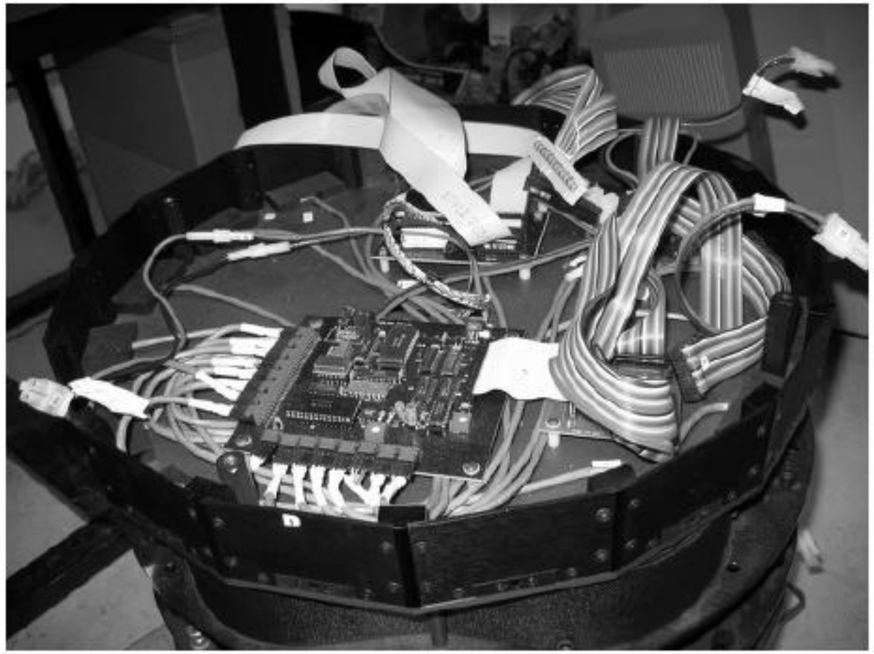


Figure 4.3. Nomadic Sensus 300 infrared proximity detector. This ring of 16 infrared sensors is connected to a small microprocessor to sequence the firing of the units and their modulation. The resulting package can be easily integrated into many mobile robot systems. Appears with the kind permission of Arjun Chopra.

Sonar (Sound navigation and ranging)

- Sonar sensing refers to range sensing using acoustic (i.e., sound) signals.
- Sonar is an active sensing technology whereby a sound signal or pulse is emitted and its reflection is subsequently received.
- The time of flight, the phase shift, and the attenuation of the signal as a function of frequency are aspects of the reflected signal that have been exploited by different types of sonar sensor.
- Sonar units at uniform angular intervals around the circumference of a mobile robot.

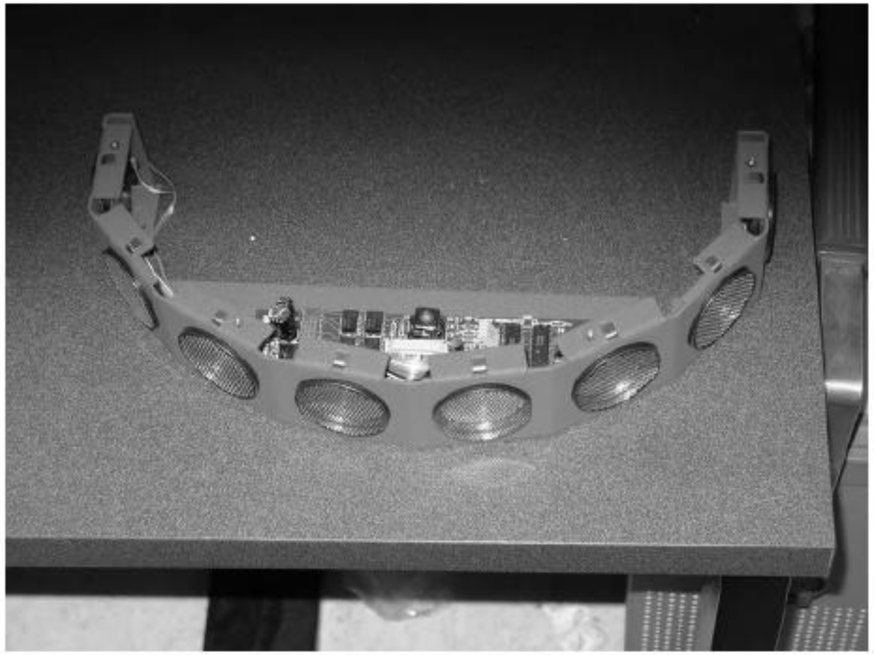
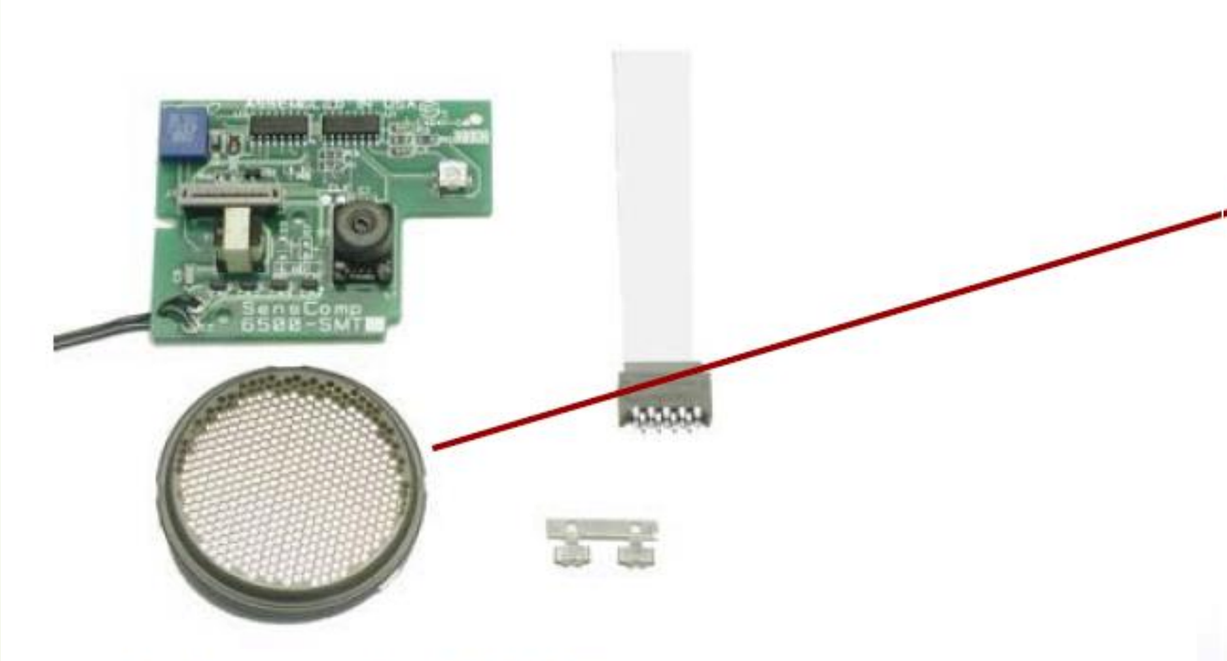


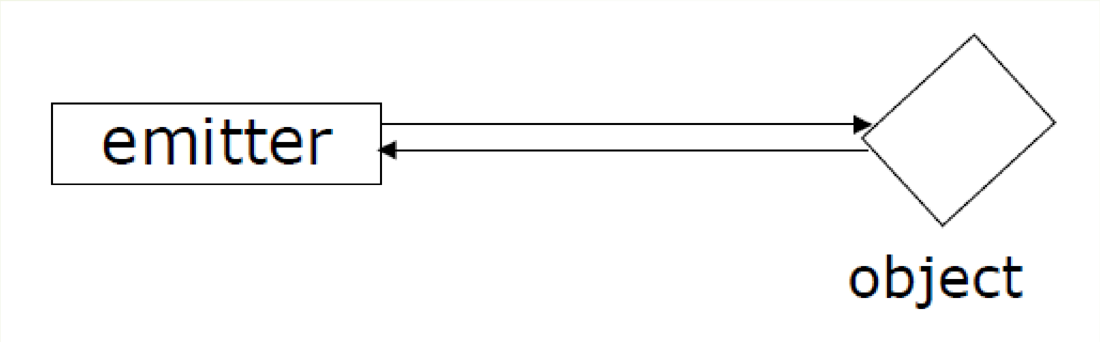
Figure 4.4. ActiveMedia Robotics P3-AT sonar sensor. Appears with the kind permission of Arjun Chopra.

- Emit a brief acoustic pulse (using a brief high-voltage, high-frequency electrical signal through the transducer)
- The acoustic frequency used in commercial sonar units is almost invariably ultrasonic, 40-50 kHz
- Wait until they receive the echo
- Time of flight sensor



Polaroyd 6500

Time of Flight Sensors



$$d = \frac{1}{2}ct$$

$$c = c_0 + 0.6T \text{ m/s}$$

- Time elapsed between broadcast of signal and reception of the echo : t
- The speed of sound in air : c, $c_0 = 331$ m/s
- The distance to the object: d

Properties of Sonar or Ultrasounds

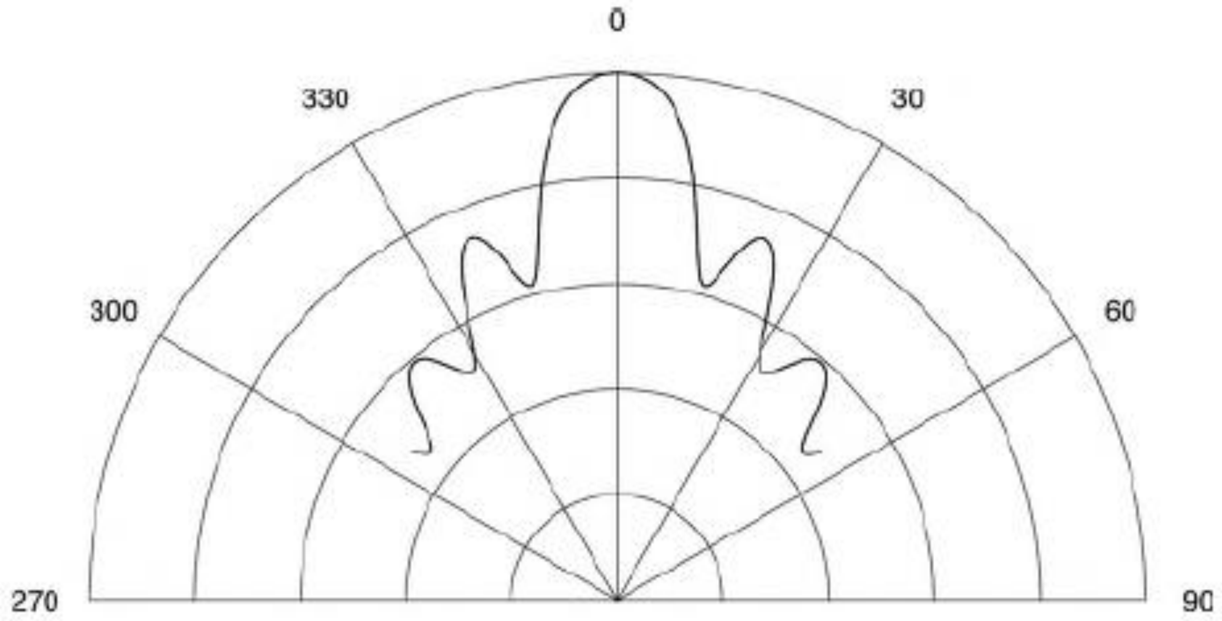
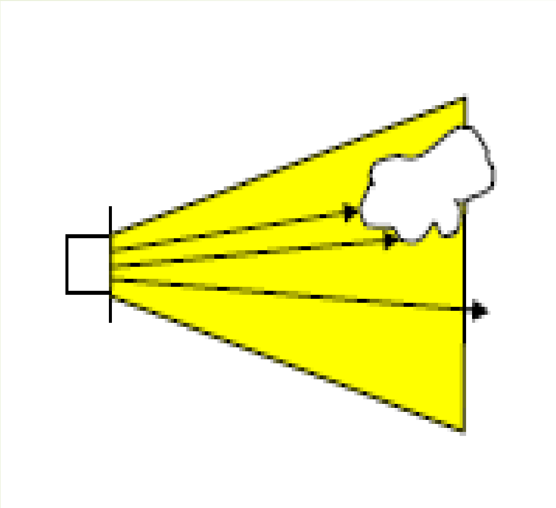
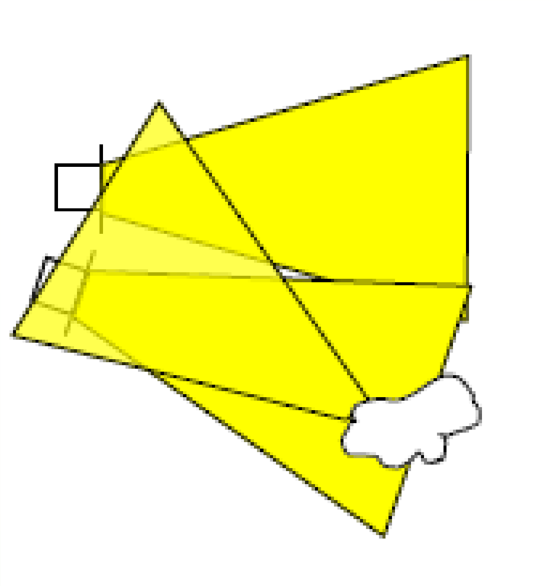


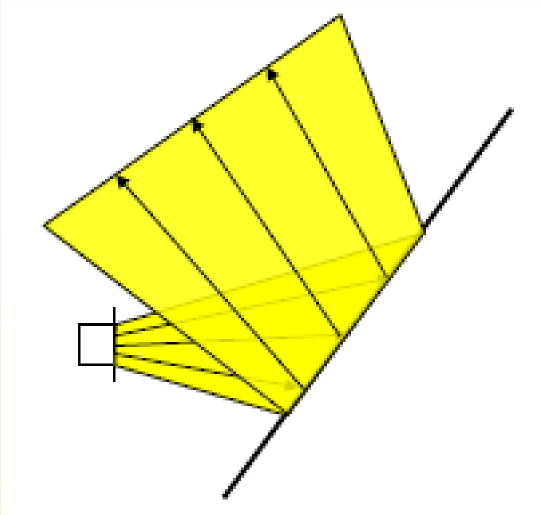
Figure 4.5. Sonar amplitude profile for the Polaroid sonar sensor: the strength of the sonar signal as a function of orientation with respect to the center of the beam. Although most of the power is restricted to a single lobe near the center of the beam, significant side lobes exist.

Sources of Error

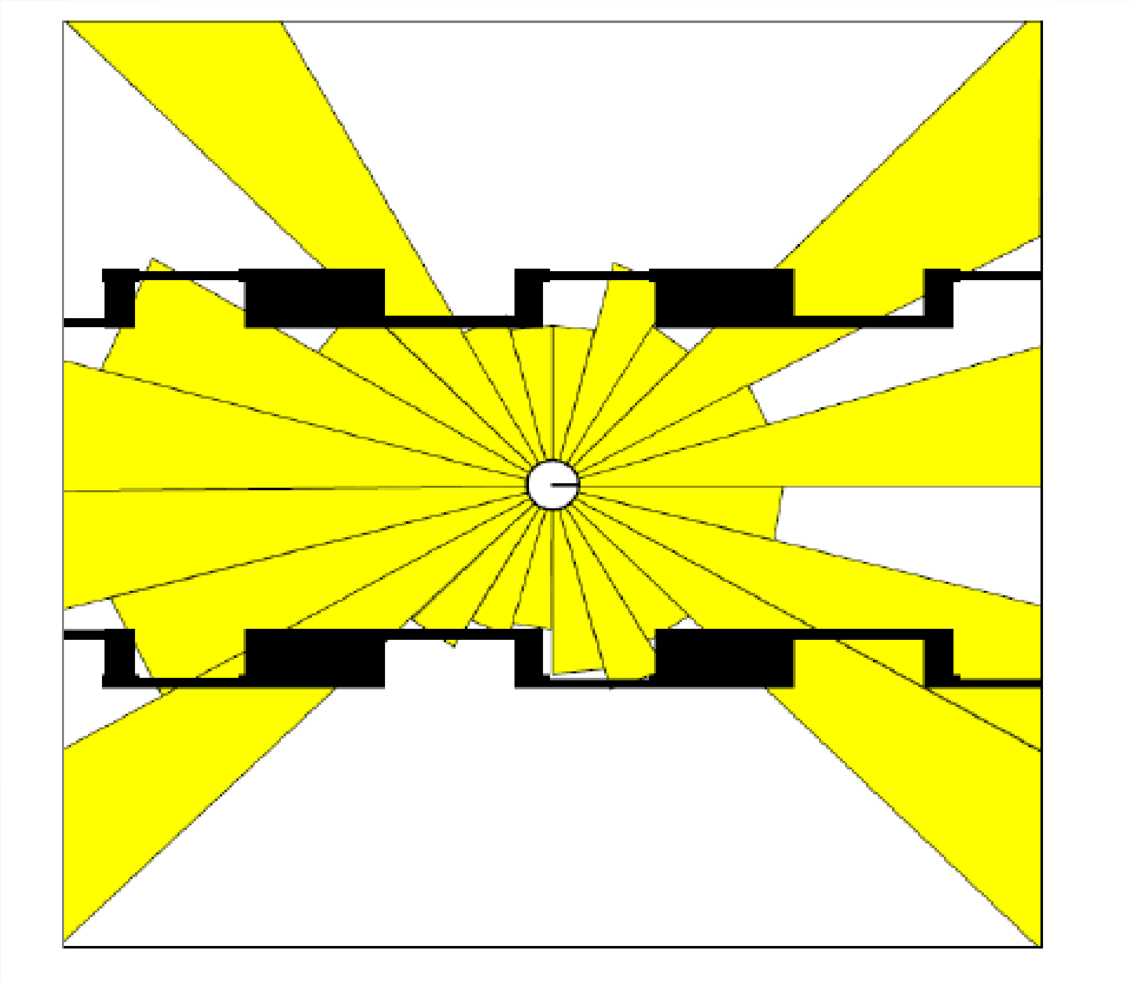
- Opening angle
- Crosstalk
- Specular reflection







Typical Ultrasound Scan



Parallel Operation

- Given a 15 degrees opening angle, 24 sensors are needed to cover the whole 360 degrees area around the robot.
- Let the maximum range we are interested in be 10m
- The time of flight then is 2*10m divided by the speed of sound (330 m/sec) which leads to 0.06sec
- A complete scan thus requires 24*0.06=1.45sec
- To allow frequent updates (necessary for high speed) the sensors have to be fired in parallel.
- This increases the risk of crosstalk

Radar (Radio Detecting and Ranging)

- High frequency radio waves are transmitted, and their reflections are observed to obtain range measurements and other properties.
- It can be used to discriminate among different terrain types, and this may be useful in estimating traversability.
- It penetrates the surface layer of an object, it can provide information of subsurface structures.
- Radar can be used in environments lacking an atmosphere
- Radar suffers from difficulties with specular reflections and with the relatively large footprint of the Radar Signal.

Laser (Light Amplification by Stimulated Emission of Radiation) Rangefinders (LIDAR)

- The sensing technology is based on measurement of the delay or the phase difference between the emitted laser signal (beam of coherent light) and returned reflection.
- As the laser beam diverges with distance, the localization of the recovered distance becomes less accurate with more remote targets.
- Laser systems are typically mounted on a pan-tilt unit or as a mirror assembly to direct the beam at different parts of the environment.
- LIDAR - is a specific utilisation of a LASER beam for detection analyzing and tracking purposes.

(a) Sick laser scanner (b) Scanner mounted on a robot

Figure 4.10. A SICK laser scanner. (a) Appears with the kind permission of Arjun Chopra.

Satellite Based Positioning

- Global Positioning System (GPS) is based on a constellation of 21 orbitting satellites (there are currently 3 spares in orbit as well).
- It allows an appropriately equipped receiver to compute its absolute position, velocity, and time to substantial accuracy.
- The system operates by allowing a user to measure the difference in time of flight for a radio signal to arrive from a combination of satellites.
- Obtaining an estimate of position requires a direct view of a minimum of four satellites and can be obtained at a rate of up to 2Hz.
- The accuracy of GPS is 1m-10m.
- Occlusion by obstacles from tree to mountains or buildings can complicate the situation.
- GPS does not function well in many environment of interest for mobile robotics. Specifically, system cannot be used indoors, underground or underwater.

Visual Sensors and Algorithms

Introduction

- Human vision relies on two eyes to transform information encoded in light into electrical signal transmitted by neurons.
- In the biological sciences, the field of **perception** and **cognition** investigate how this neural information is processed to build internal representations of the environment and how humans reason about their environment using these representations.
- From a robotics point of view, the fields of **computer vision** and **robot vision** examine the task of building computer representations of the environment from light and the study of **artificial intelligence** deals in part with the task of reasoning or planning based on the resulting environmental representation.
- A fundamental difficulty with using vision as a robotic sensor is that a single image of an object generally does not determine the object's absolute distance or size.
- The extraction of depth information from one or more images requires a strong model of the process of image acquisition (**camera calibration**) and a representation of the raw image data in some intermediate form in terms of image features.

References

- Introduction to Autonomous Mobile Robots, Roland Siegwart and Illah R. Nourbakhsh, 2004, Chapter 4
- Computationaş Principles of Mobile Robotics, Gregory Dudek and Michael Jenkin, 2010, Chapter 4 and 5