Topic 5: External Sensors for Navigation

Tactile, Proximity, Range, Triangulation

5.1 Introduction

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5.3 Proximity sensors

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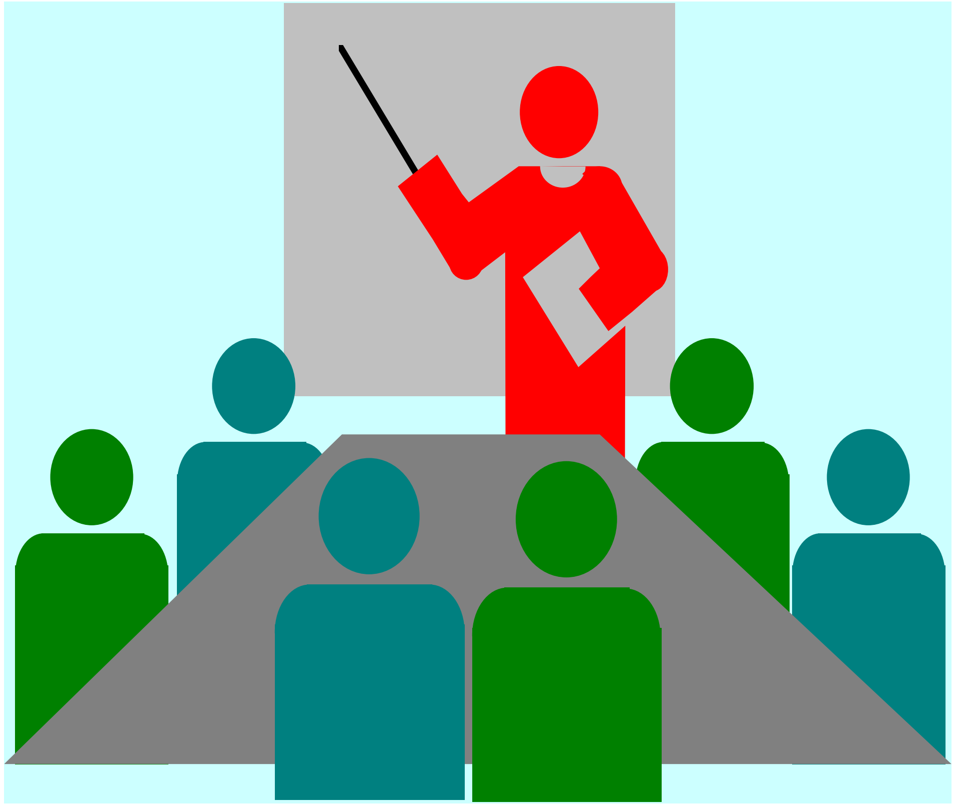
5.5 Triangulation techniques

5.6 Summary



5.1 Introduction

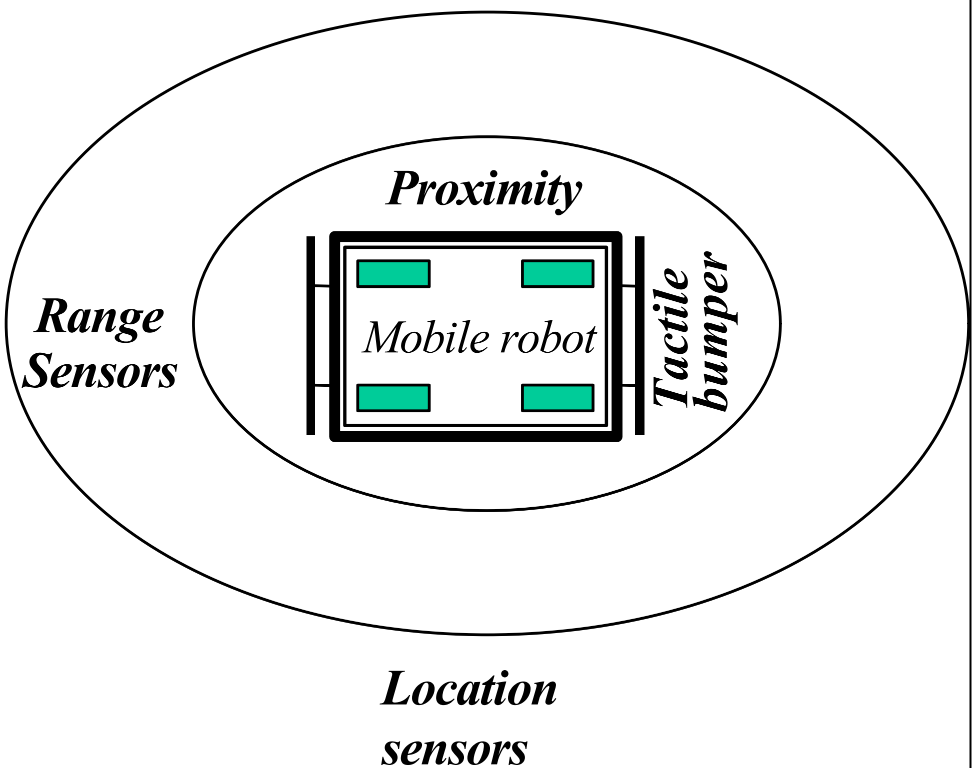
External sensors in a mobile robot

Main functions:

-- to locate the robot with respect to the environment in order to travel around and implement a specific task.

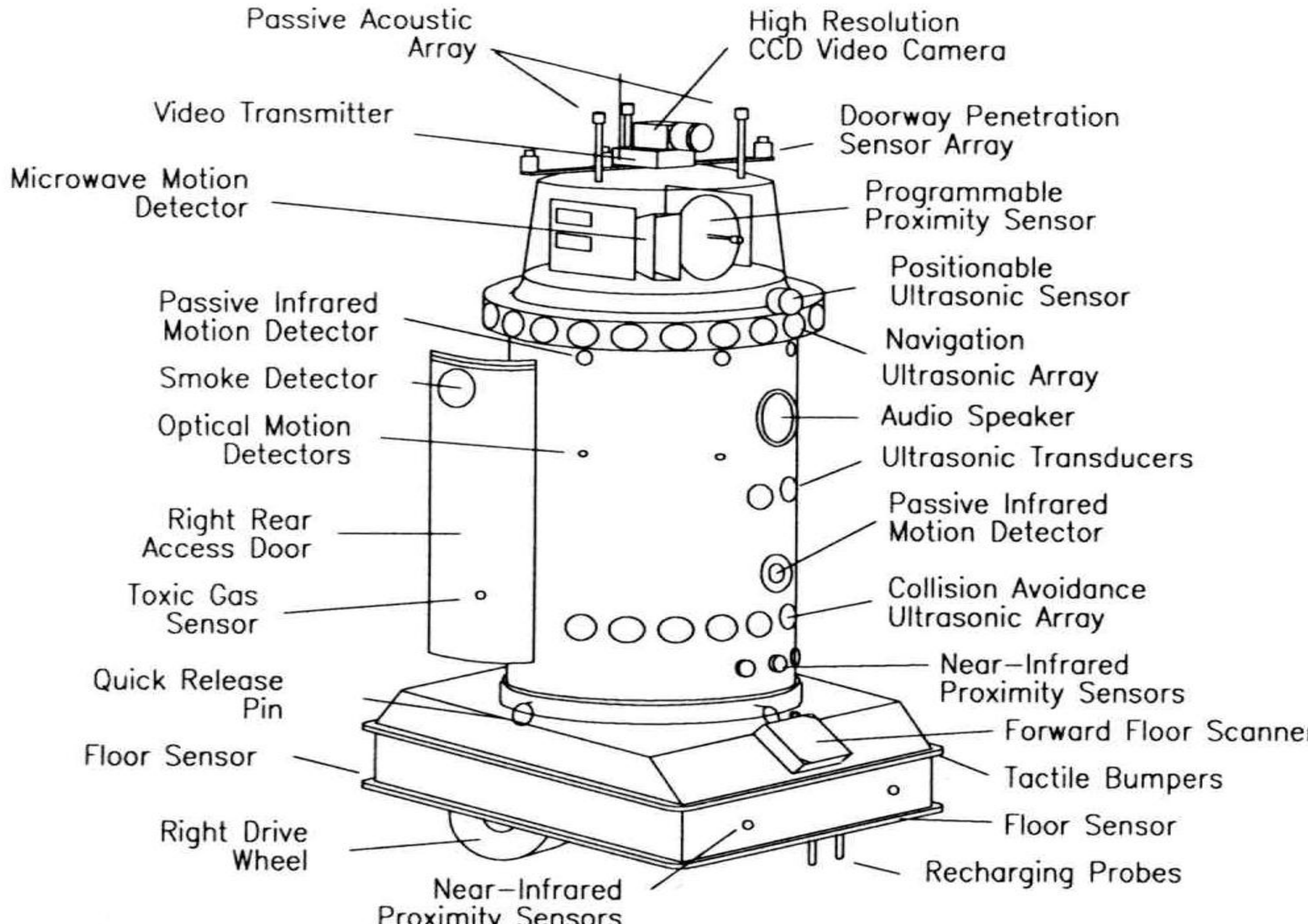
-- to locate objects in the environment with respect to the robot in order to handle them and avoid collision.

-- to provide real data to update maps within the robotic systems for path planning and environment learning.



5.1 Introduction

Robart II
H.R. Everett,
USA, 1990s



5.2 Tactile Sensing

5.2.1 Why tactile sensing:

- Tactile sensing is relatively simple (switches, strain gauges, pressure transducers), and more economical than other sensors such as vision.
- Tactile sensing allows a robot to analyse environments that cannot be seen due to inadequate illumination or object obstruction.
- It provides information about the contact between objects & the robot.

Two main applications:

- Emergency stop of mobile robots at the front of obstacles
- Dedicated assembly operations of industrial robots in manufacturing

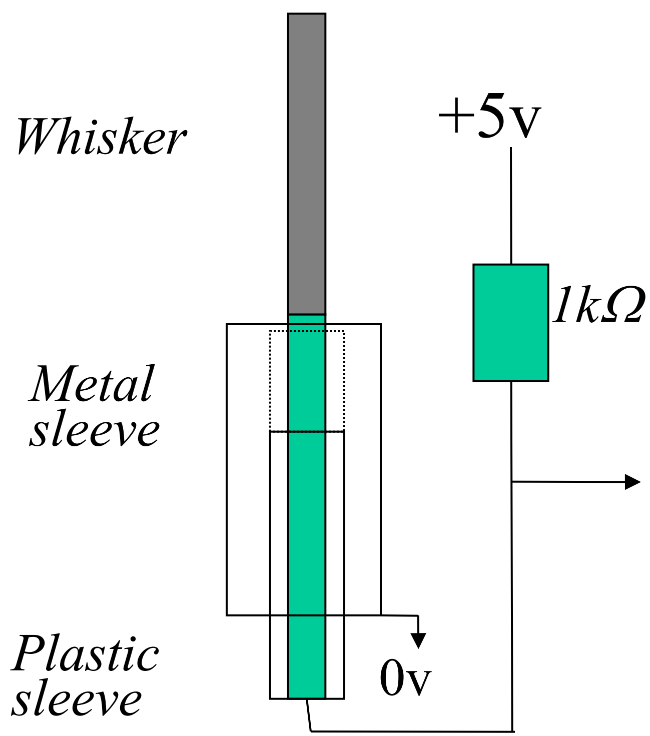
Three fundamental operations:

- Joint forces: sensing the force applied to the robot wrist and arm joints
- Touch: sensing the pressures applied to various points
- Slip: sensing any movement of the object being grasped

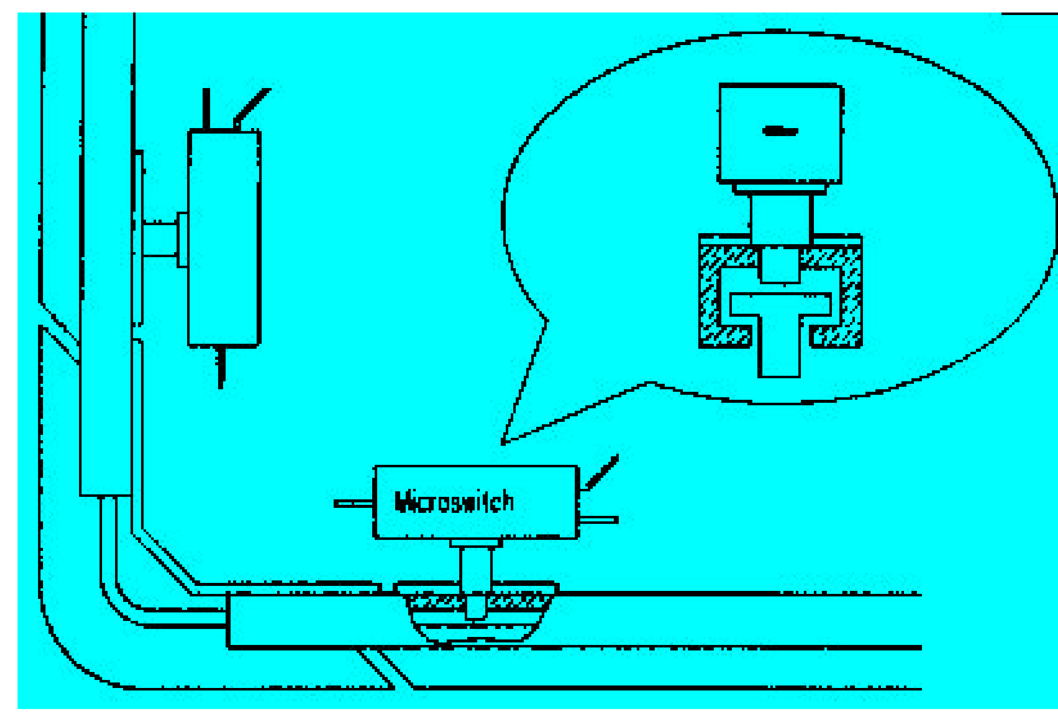
5.2.2 Tactile Sensors for Mobile Robots

Two popular tactile sensors in mobile robots:

(i) tactile whiskers; (ii) tactile bumpers.



Tactile feeler

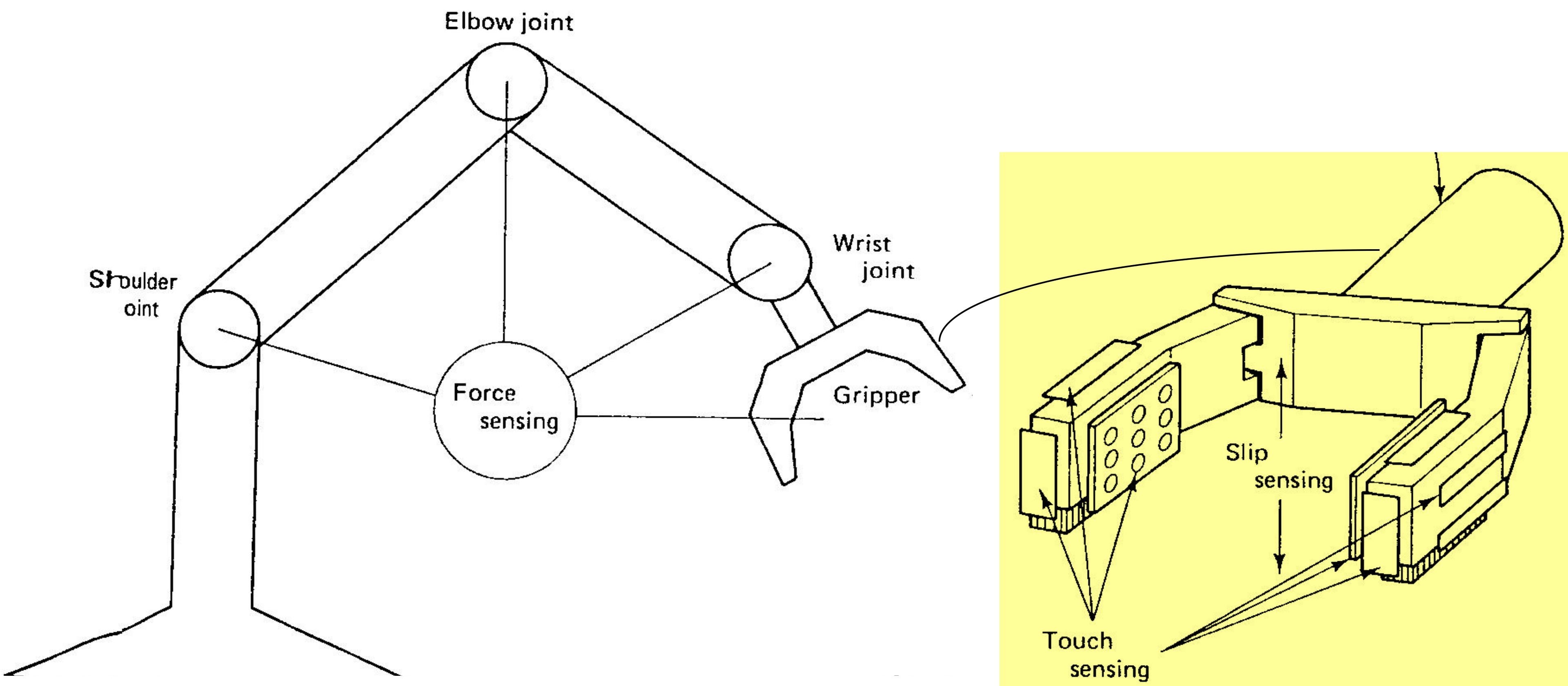


Tactile bumper

5.2.2 Tactile Sensors for Mobile Robots

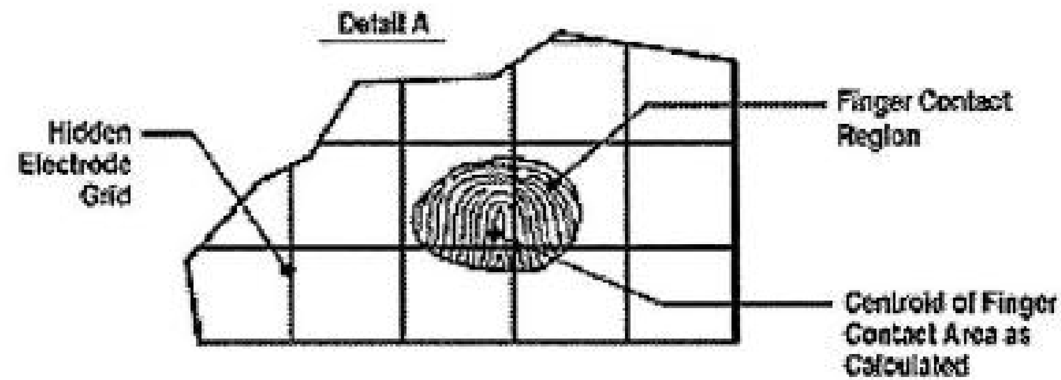
5.2.3 Tactile Sensors for Industrial Robots

A complete tactile sensing system



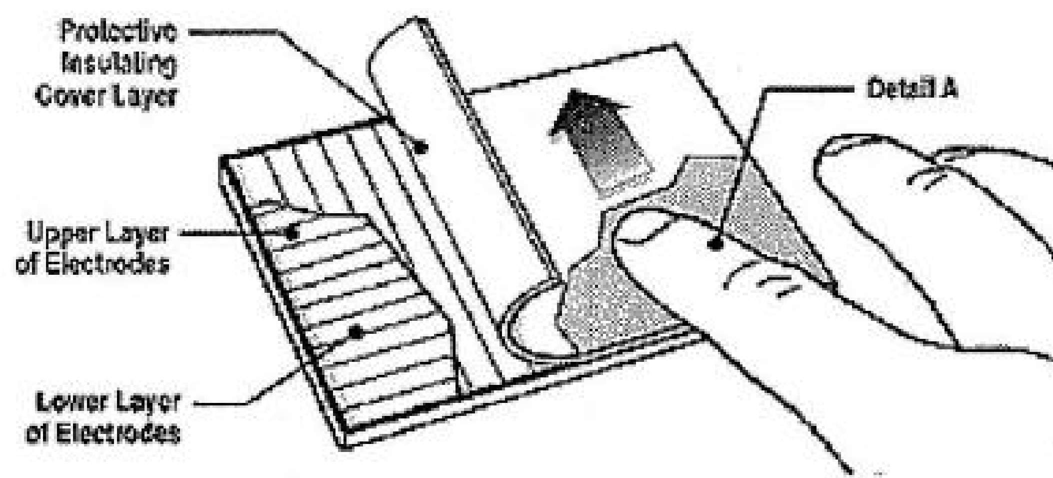
5.2.4 Tactile Sensors for Electronic devices

Touch pads & touch screens



- It contains a two-layer grid of electrodes.
  - Upper layer - vertical strips.
  - Lower layer – horizontal strips

- Capacitive
- Resistive
- Acoustic

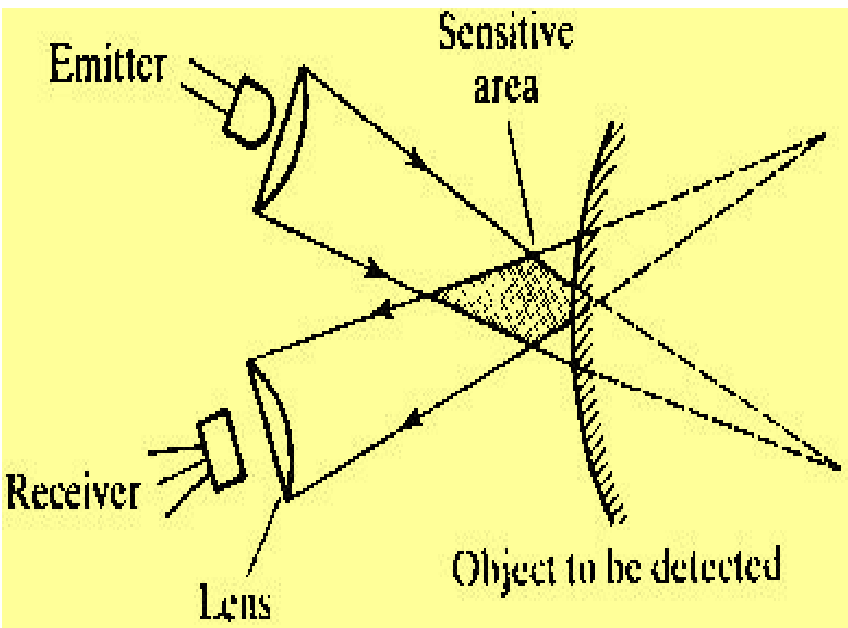


5.2.4 Tactile Sensors for Electronic devices

5.3 Proximity Sensors

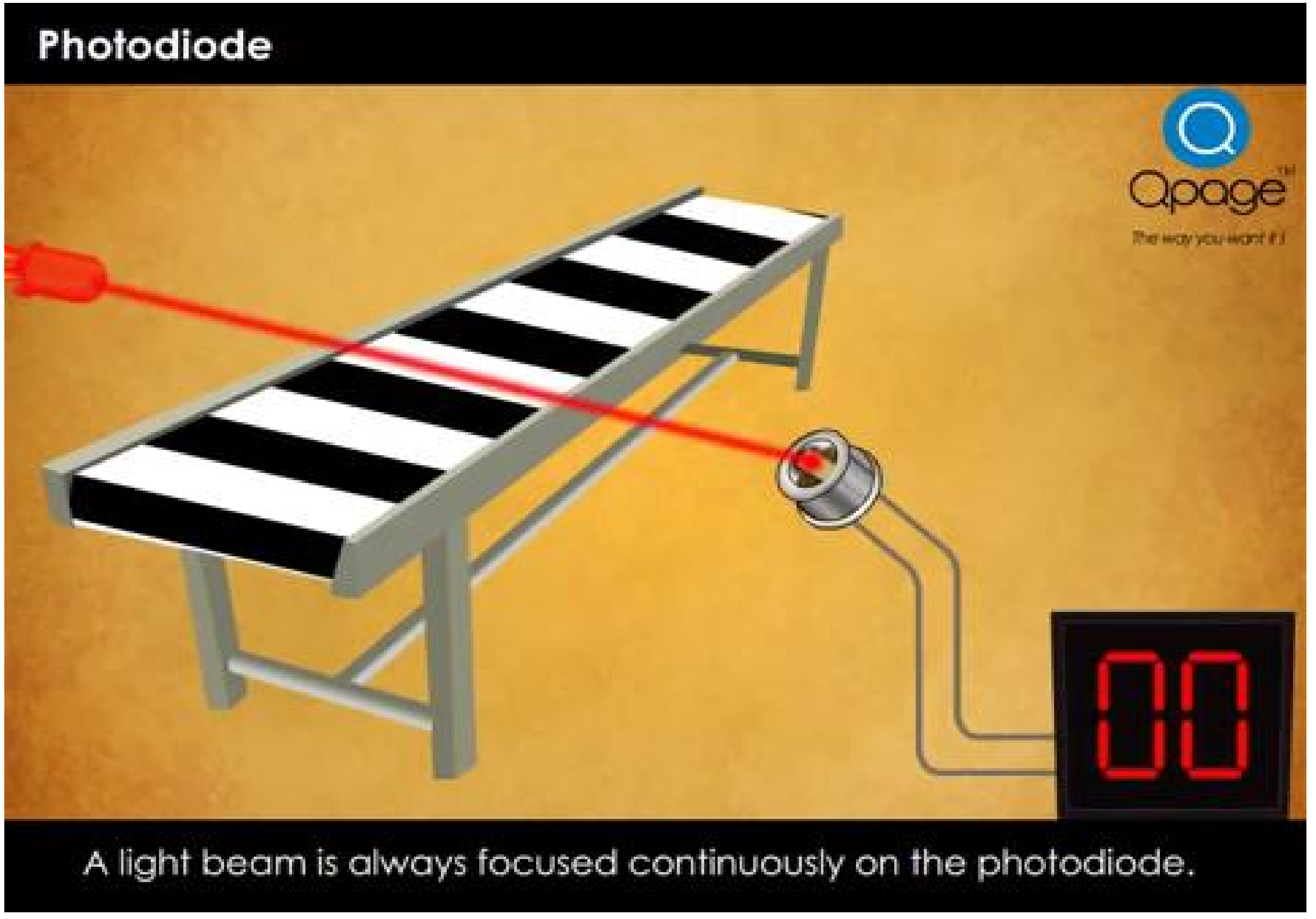
Three principles are used in the design of proximity detectors:

(i) *Diffuse mode*



5.3 Proximity Sensors

(ii) *Beam blocking mode*

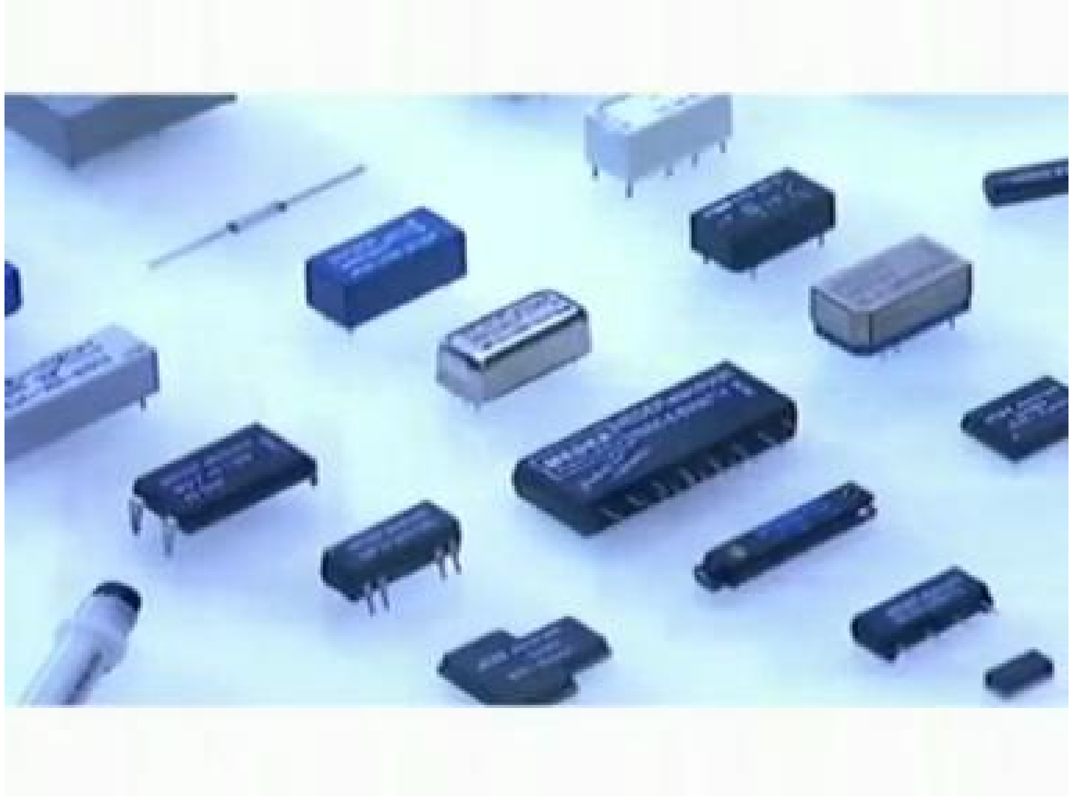


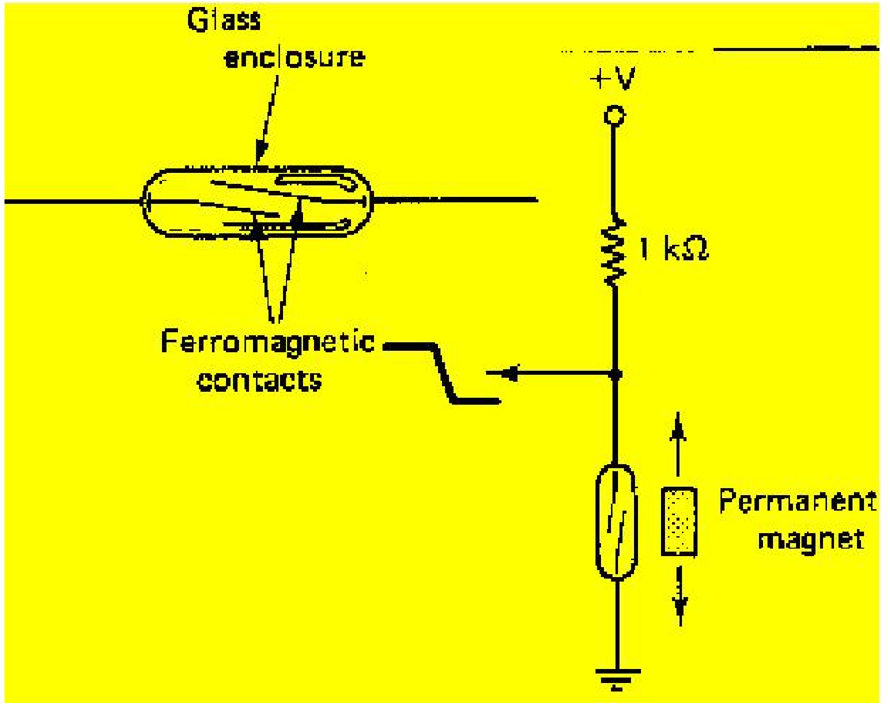
5.3 Proximity Sensors

(iii) *Disturbance in the environment*

5.3 Proximity Sensors

(ii) *Disturbance in the environment*





(b) Magnetic reed switch

Output = on/off

5.4 Range Finding Sensors

5.4.1 Why range finding sensors?

Range finding sensors directly measure the distance to objects:

-- detecting objects in the robot surrounding area for collision avoidance
-- providing information for a robot to build environment maps
-- locating objects for a robot to do manipulation

Range finding sensors are mainly based on the following ranging techniques:

-- *Time of flight*: measuring range by counting the travel time
-- *Phase shift measurement*: using a continuous-wave signal
-- *Triangulation*: measuring range by geometry
-- *Frequency modulation*: using a continuous-wave signal
-- *Interferometer*: measuring movement
-- *Range from focus*: based on *Gauss thin lens law*
-- *Return signal intensity*: measuring the amplitude of energy

5.4.2 Time-of-flight Range Finders

1. The Principal of time-of-flight ranging systems

They measure the time it takes for a signal (*Ultrasonic, Radio Frequency, or Optical energy sources*) to reach & return from an object.

The range to an object is calculated by: $$R = \frac{vt}{2}$$

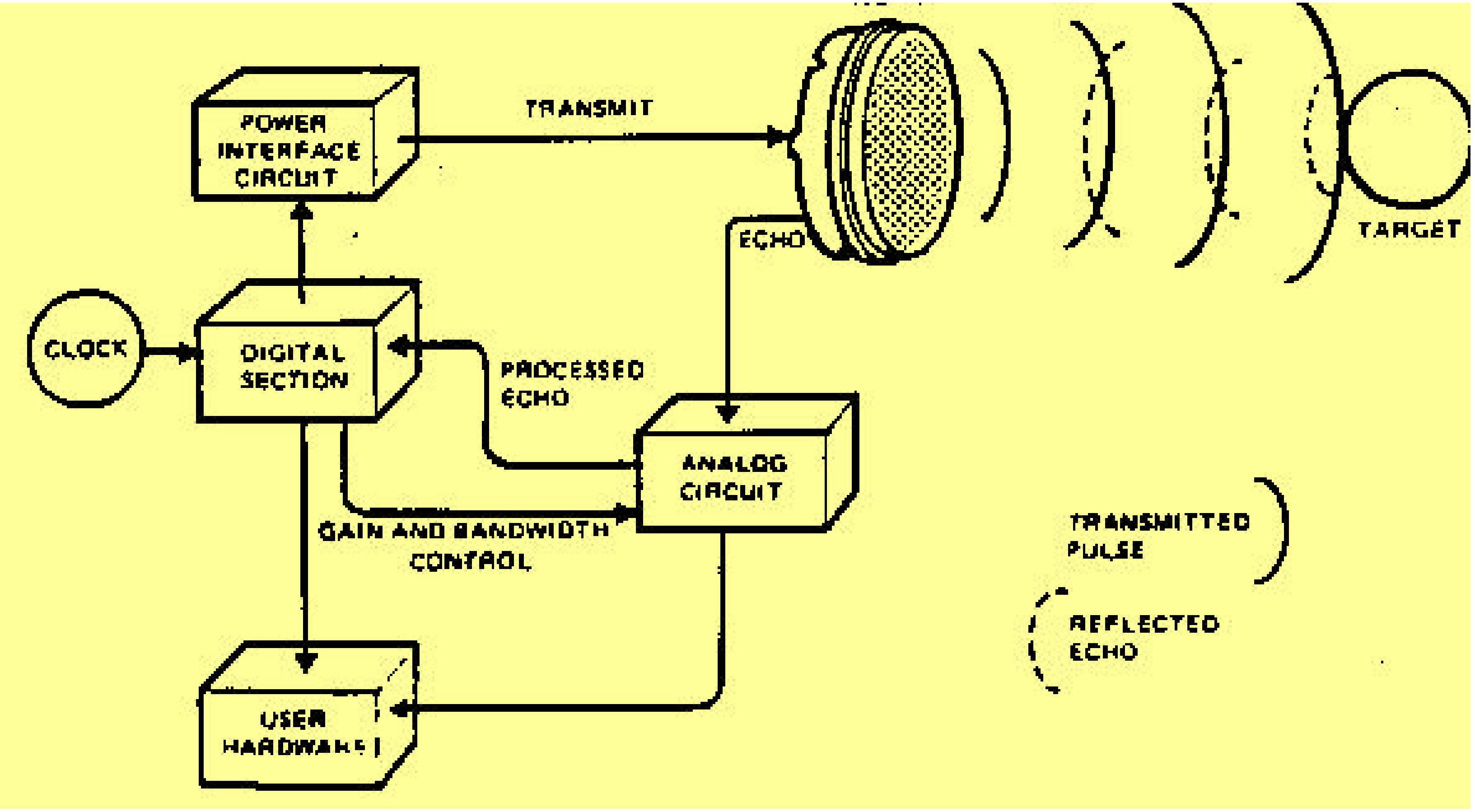
where: R is the range being measured. v is the velocity of the signal being transmitted (**the sound speed:** 343 m/s, **the light speed:** 300,000,000m/s).
t is the time travelled.

Note: the width of a signal beam determines the amount of detail being detected:

- A wide signal beam has a lower resolution and cannot decide the precise angle of an object being detected.
- A narrow signal beam has higher resolution but may misses a small target.

5.4.2 Time-of-flight Range Finders

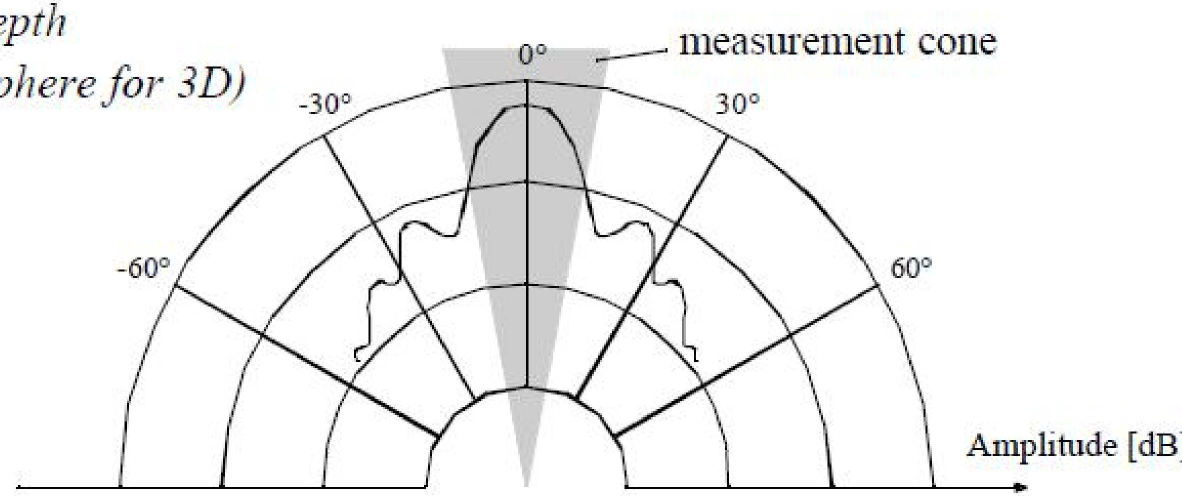
2. Ultrasound ranging finder or Sonar (sound navigation and ranging)



5.4.2 Time-of-flight Range Finders

Ultrasound ranging finder *or* ***Sonar*** (**so**und **n**avigation **a**nd **r**anging)

- typically a frequency: 40 - 180 kHz
- generation of sound wave: piezo transducer
  - *transmitter and receiver separated or not separated*
- sound beam propagates in a cone like manner
  - *opening angles around 20 to 40 degrees*
  - *regions of constant depth*
  - *segments of an arc (sphere for 3D)*

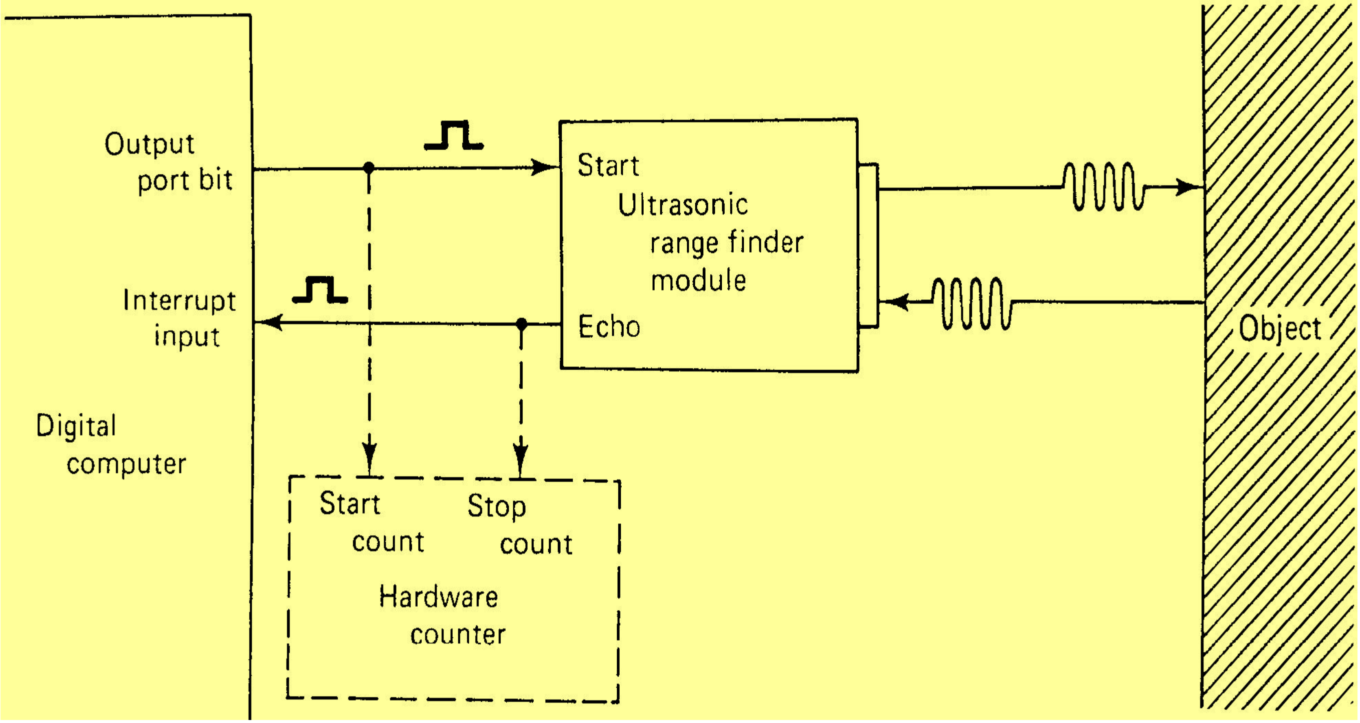


Typical intensity distribution of a ultrasonic sensor

5.4.2 Time-of-flight Range Finders

Example:

An ultrasonic range finder *generates a sound burst that consists of 16 cycles at 50KHz. At the same time, a 16-bit counter is adopted based on 1MHz clock.*



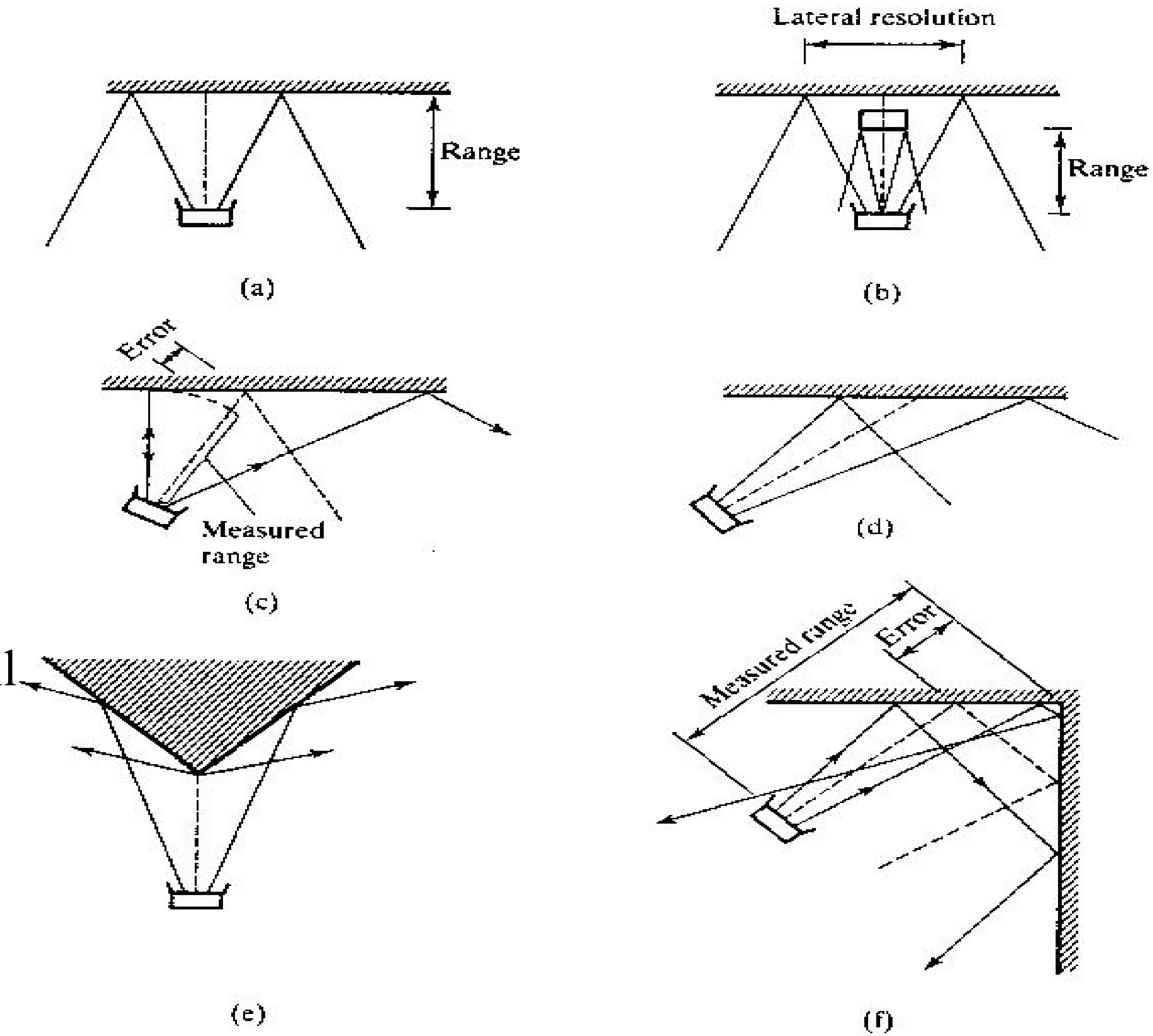
(a) What is the maximum range of this system?
(b) What is the maximum possible resolution of the system?
(c) What is the range of an object if the counter contains the value 15663 when it is disabled by a returning signal?

5.4.2 Time-of-flight Range Finders

Two main problems in sonars:

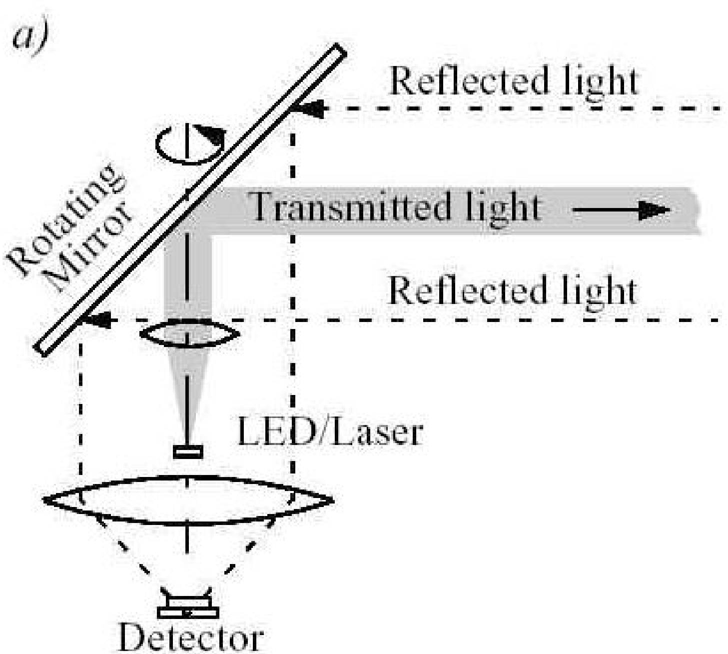
- *Specular reflection*
  The wavelength of a sonar beam is much larger than the roughness of indoor surfaces, i.e. mirror-like reflection.

- *Diffuse reflection*
  When the beam falls on a rough surface is reflected in all direction, which may bounce back to the sensor from other objects.



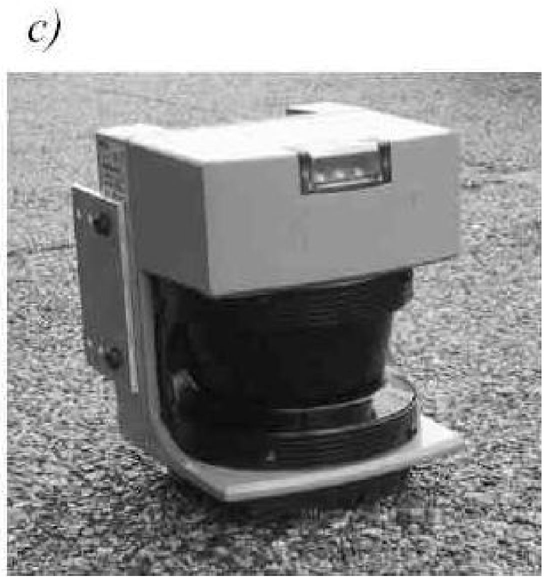
5.4.2 Time-of-flight Range Finders

3. **Laser ranging finder**



(a) Schematic drawing of laser range finder

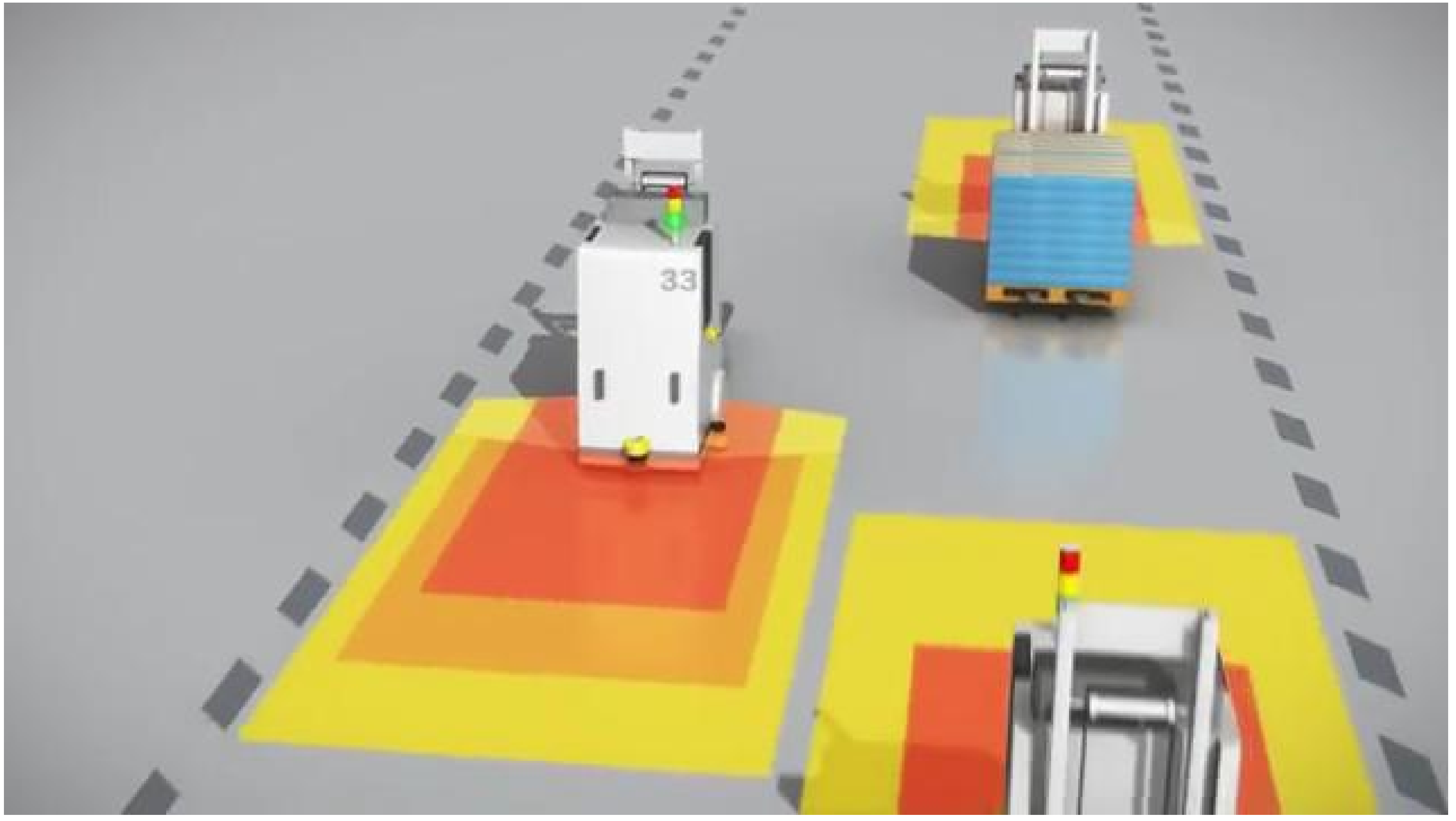
(b) Scanning range finder from EPS Technologies Inc.



(c) Industrial 180 degree laser scanner from SICK Inc., Germany

5.4.2 Time-of-flight Range Finders

2. Laser scanning for safety:



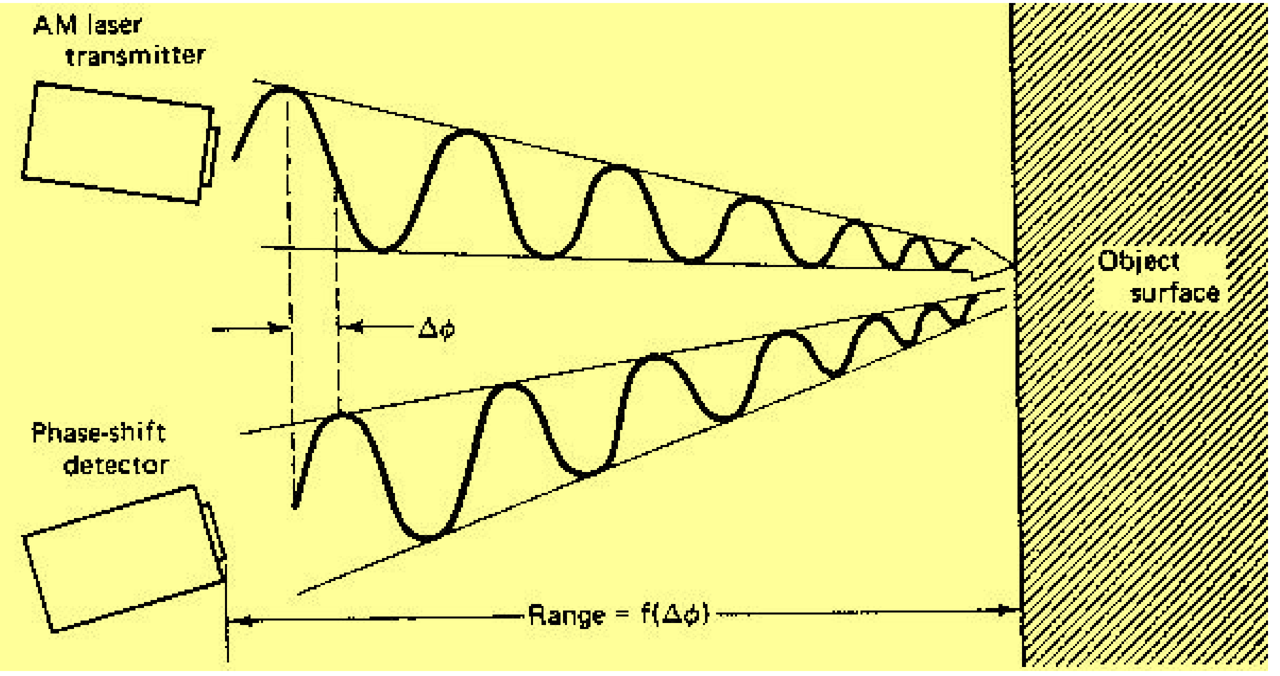
5.4.3 Phase Shift Measurement

A light detection & ranging system

- A light detection is normally implemented by phase shift measurement.
- The light beam is amplitude modulated and transmitted.
- The signal reflected from an object is out of phase with the original signal.
- The amount of phase difference is proportional to the range of the object.

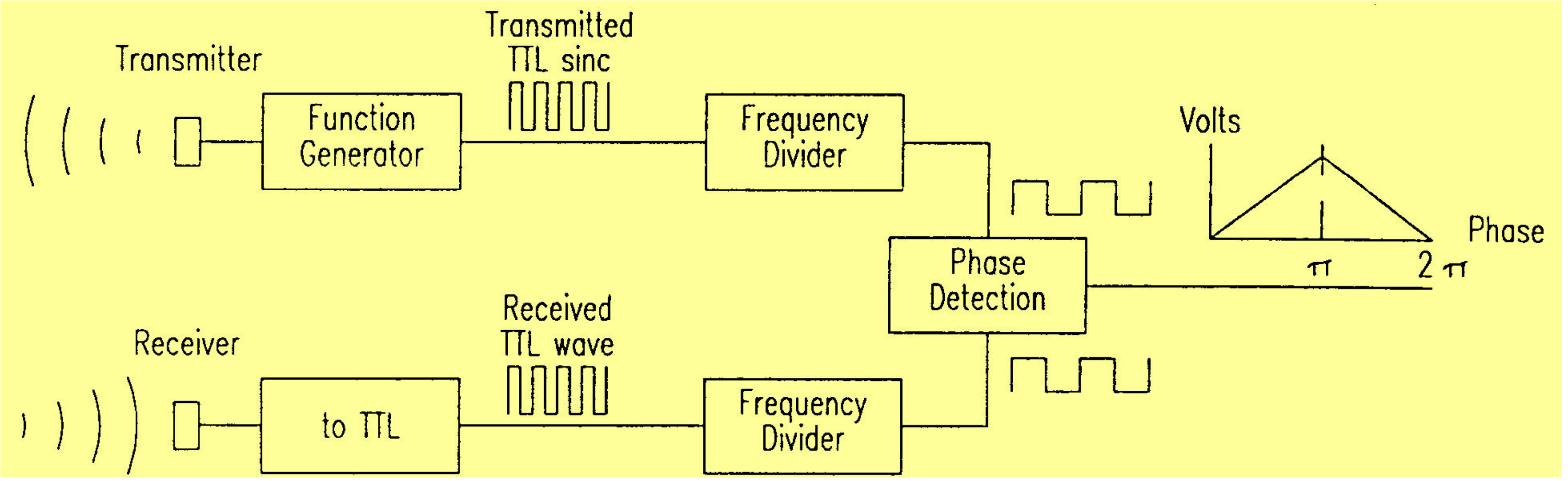
$$d = \frac{\phi \lambda}{4 \pi} = \frac{\phi c}{4 \pi f}$$

where ϕ*=phase shift;*
d=distance to target;
λ*=modulation wavelength;*
c=speed of light;
f=modulation frequency.



5.4.3 Phase Shift Measurement

The design for phase shift measuring within 360 degrees:



Note: *The phase measurement becomes ambiguous once* ϕ *exceeds* 2π.

Question: What is the range of the object if a laser light modulated at a frequency 1 MHz has a phase shift 1 radian between the transmitted signal and the received signal?

5.5 Triangulation Techniques

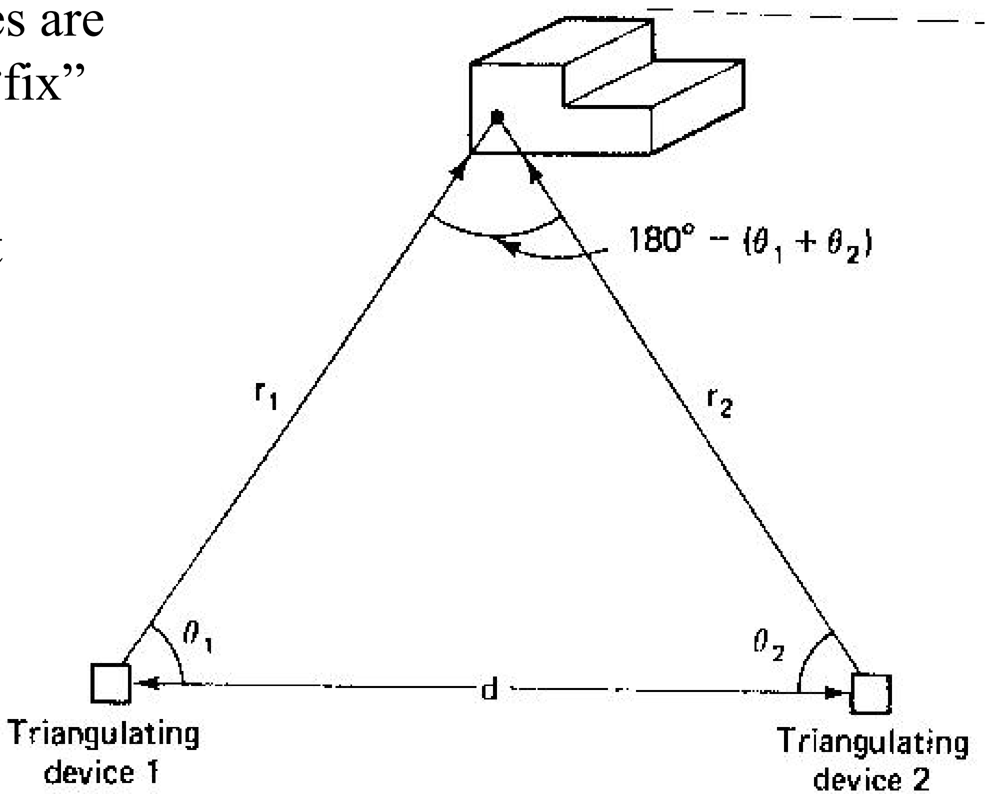
5.5.1 Triangulation Range Measurement

Using triangulation to measure distance is straightforward. Suppose two sensor devices are a certain distance apart and both can get a "fix" on an object as shown in the figure.

The distance from each device to the object can be found using the *law of sines:*

$$r_1 = \frac{d \sin \theta_2}{\sin [180^\circ - (\theta_1 + \theta_2)]}$$

$$r_2 = \frac{d \sin \theta_1}{\sin [180^\circ - (\theta_1 + \theta_2)]}$$

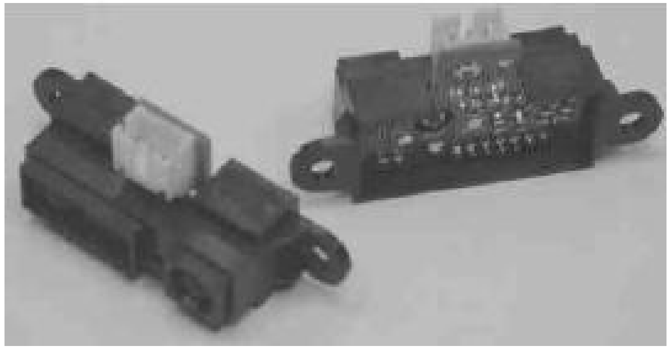


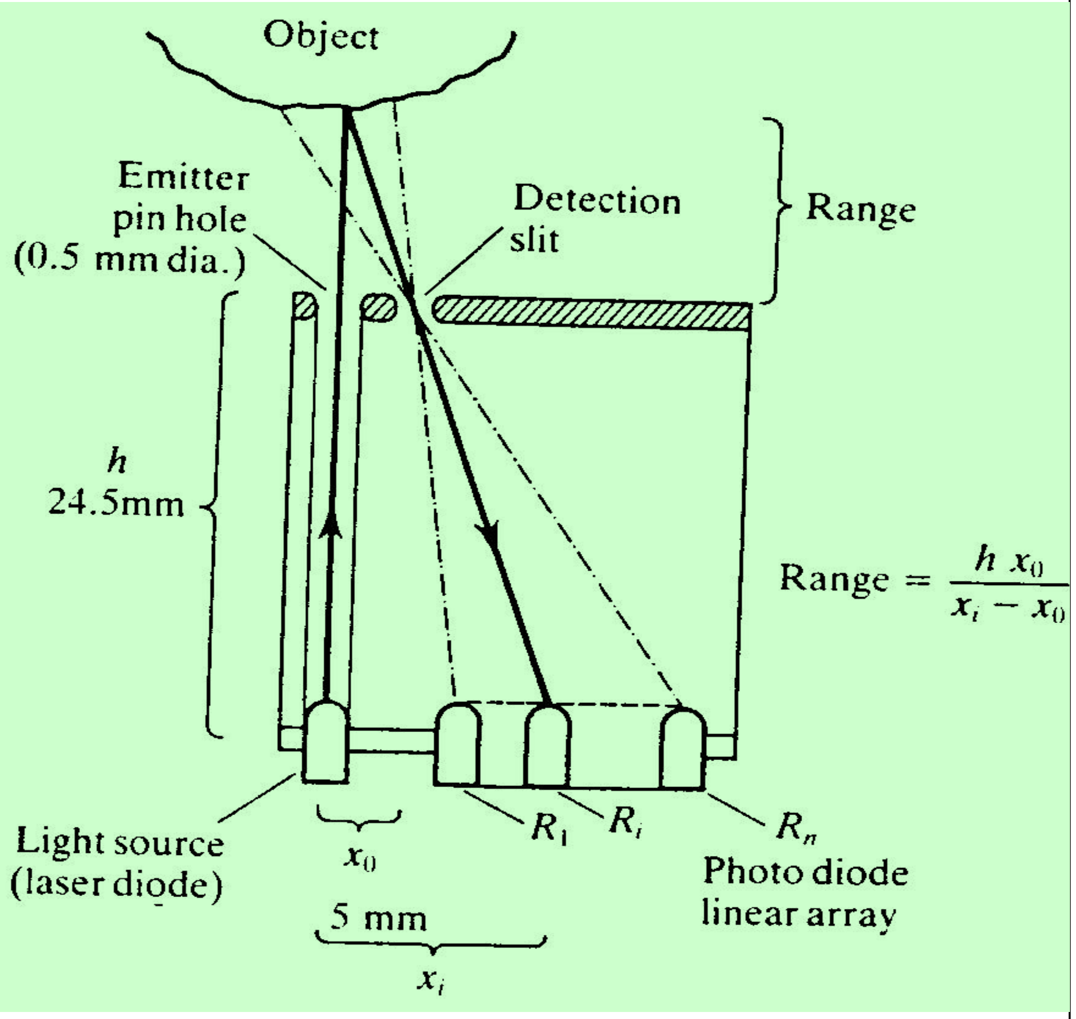
Note that two sensor devices could be laser transmitter & receiver. Or they could be two cameras.

5.5.2 Triangulation Range Measurement

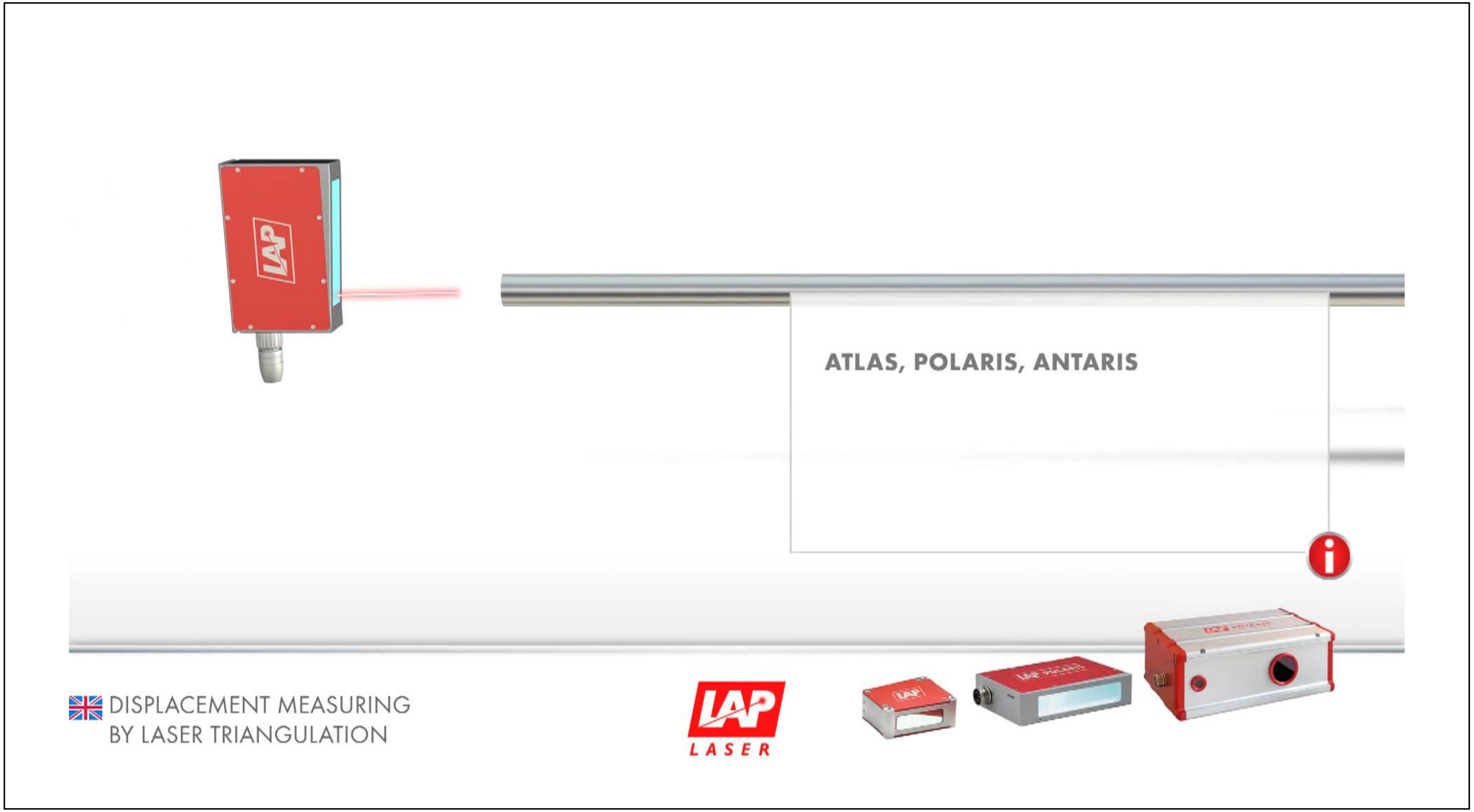
1D laser triangulation sensor

- A laser diode is used as a light source.
- A linear photo-diode array is used as a detector.
- The emitter pin-hole is for preventing light reflecting inside the sensor.
- The light beam passes through the detection slit on to the diode array.
- The sensor has active range: 5-60mm.





5.5.2 Triangulation Range Measurement



5.5.3 Passive Triangulation

Passive Triangulation

- Passive triangulation is also referred to as *stereo* or *binocular* vision.
- The distance between the cameras, *d*, and the focus length of the cameras, *f*, are known.
- The range, *r*, from the cameras to the object point is inversely proportional to the disparity between x_1 and x_2.
- The range becomes infinite, as the *disparity* approaches 0.

$$r = \frac{d\sqrt{f^2 + x_1^2 + x_2^2}}{\left| x_1 - x_2 \right|}$$

where d = distance between camera lens centers.

x_1= distance of the image pixel from the center of the left camera lens

x_2= distance of the image pixel from the center of the right camera lens

5.5.3 Passive Triangulation

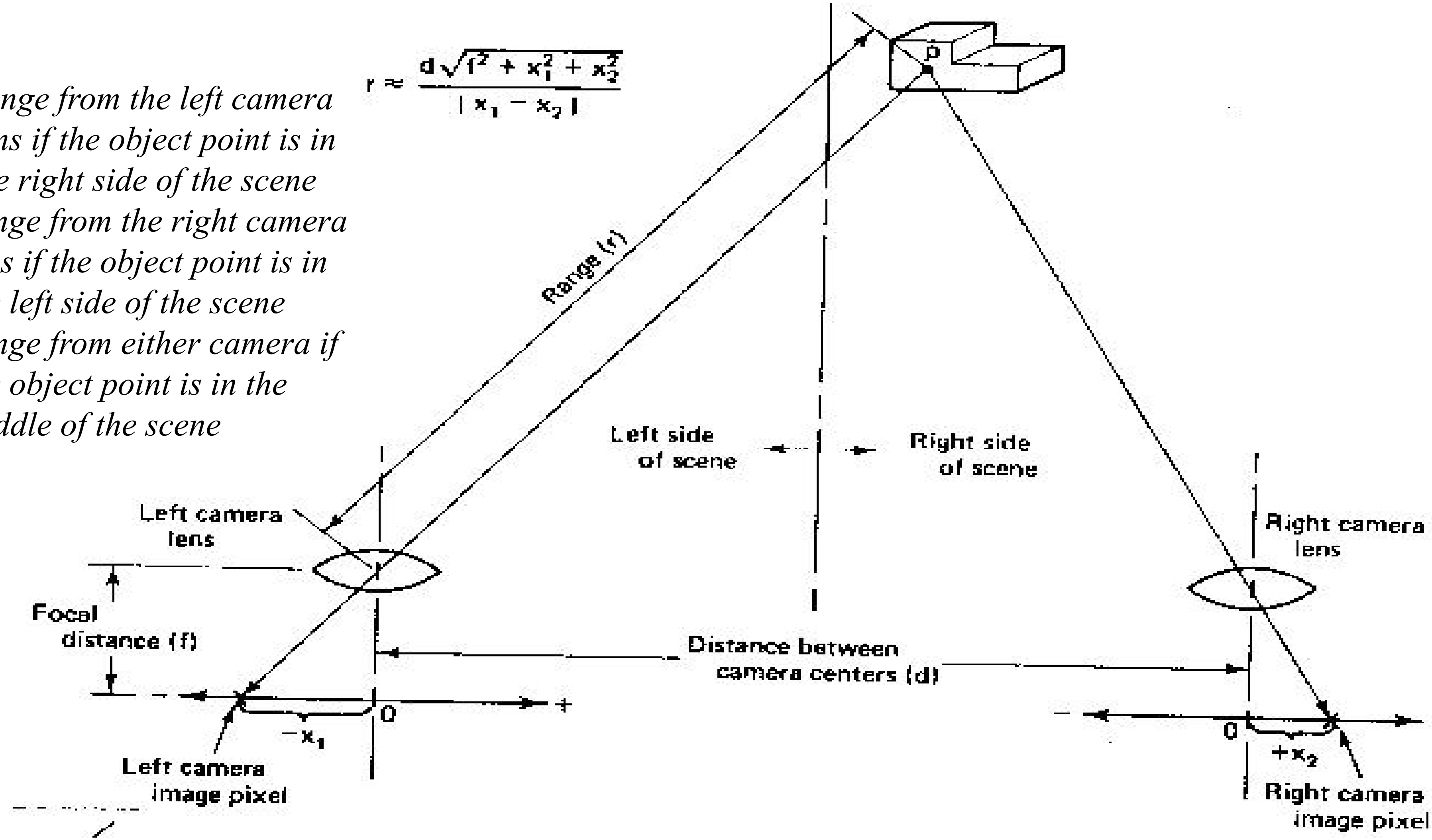
Note:

r = range from the left camera lens if the object point is in the right side of the scene

r = range from the right camera lens if the object point is in the left side of the scene

r = range from either camera if the object point is in the middle of the scene

$$r \approx \frac{d\sqrt{f^2 + x_1^2 + x_2^2}}{|x_1 - x_2|}$$



5.5.3 Passive Triangulation

5.5.3 Passive Triangulation

Correspondence problem:

- The correspondence problem is to match corresponding image points of an object from two different images.
- To match, it is necessary to search for similar edge or region features between two images as it is difficult to match individual pixels.
- Objects don't look the same from two different views.
- Objects in one image might be obscured and not even appear in a 2nd image.

Example: Two cameras having a focal length $f = 5$cm are located 30cm apart. An object is detected in the right half of the scene, between the two cameras. A pixel point representing the object is located at a distance of 0.4cm from the center of the left camera lens. The corresponding right camera pixel point is located 0.2cm from the center of its camera lens. What is the range of the object point?

5.5.4 Active Triangulation

Active triangulation is also called: Spot sensing

-- the projected light beam creates a light spot on the object that is reflected into a camera with a known distance.

The reflected light spot produces an image point, x, in the camera image. It is easy to detect since it is the *brightest spot* in the image. Since the focal length f, the distance d, and the light beam angle θ_1 are known, the range r can be calculated using *the law of sines* as follows:

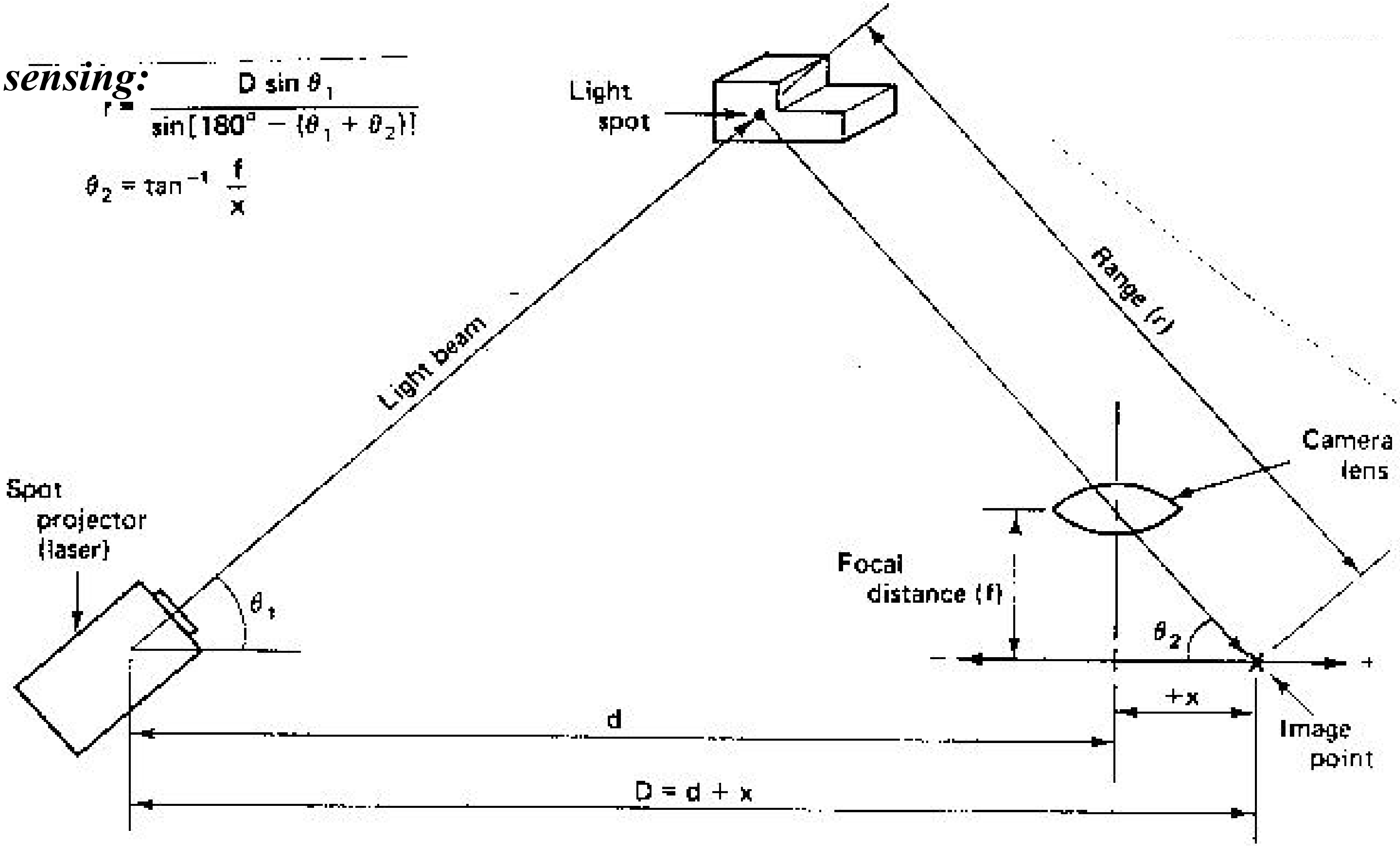
$$\frac{r}{\sin\theta_1} = \frac{D}{\sin[180 - (\theta_1 + \theta_2)]}$$

5.5.4 Active Triangulation

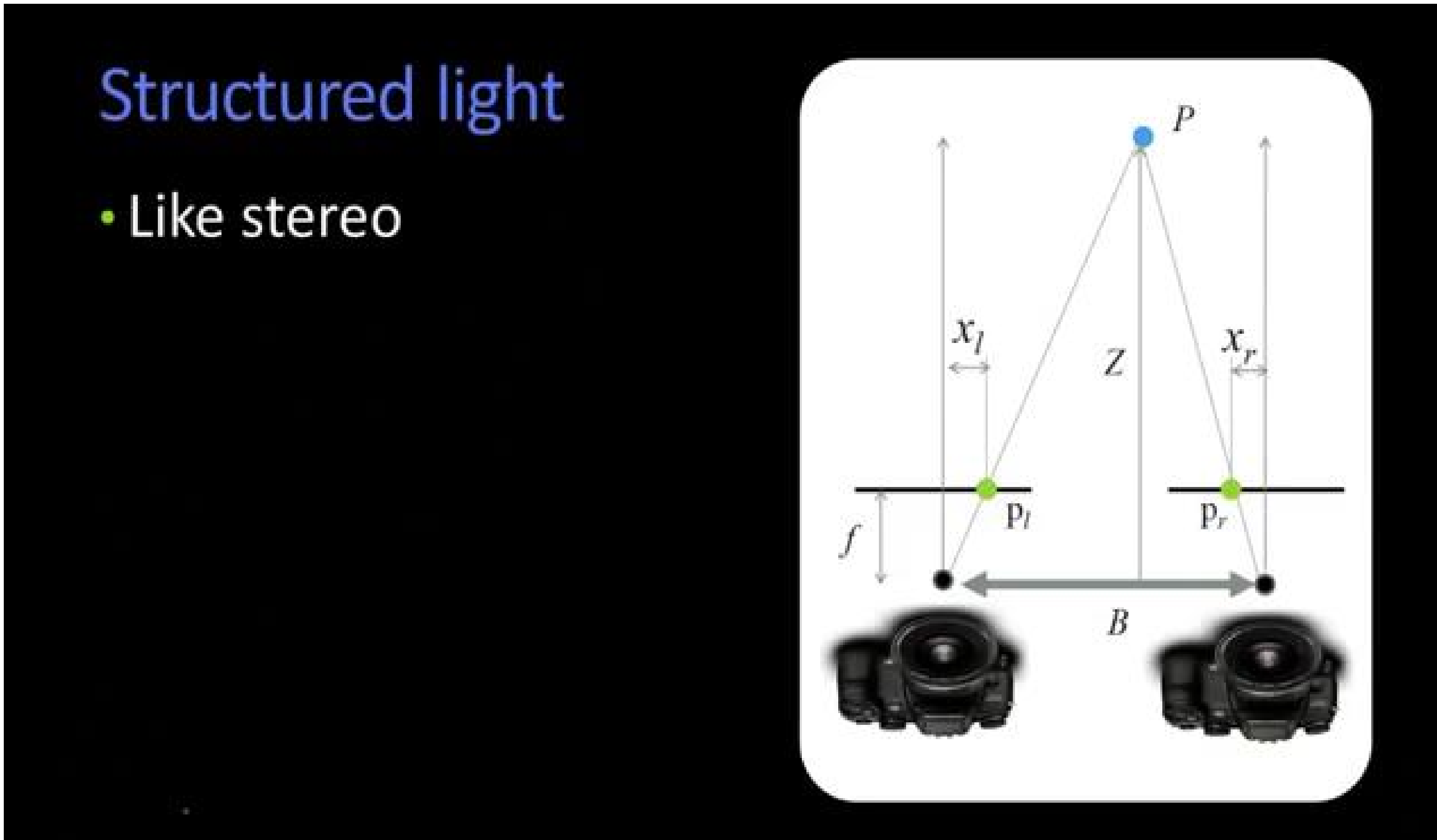
Spot sensing:

$$r = \frac{D \sin \theta_1}{\sin[180^\circ - (\theta_1 + \theta_2)]}$$

$$\theta_2 = \tan^{-1} \frac{f}{x}$$



5.5.4 Active Triangulation



5.5.5 Structure Sensing

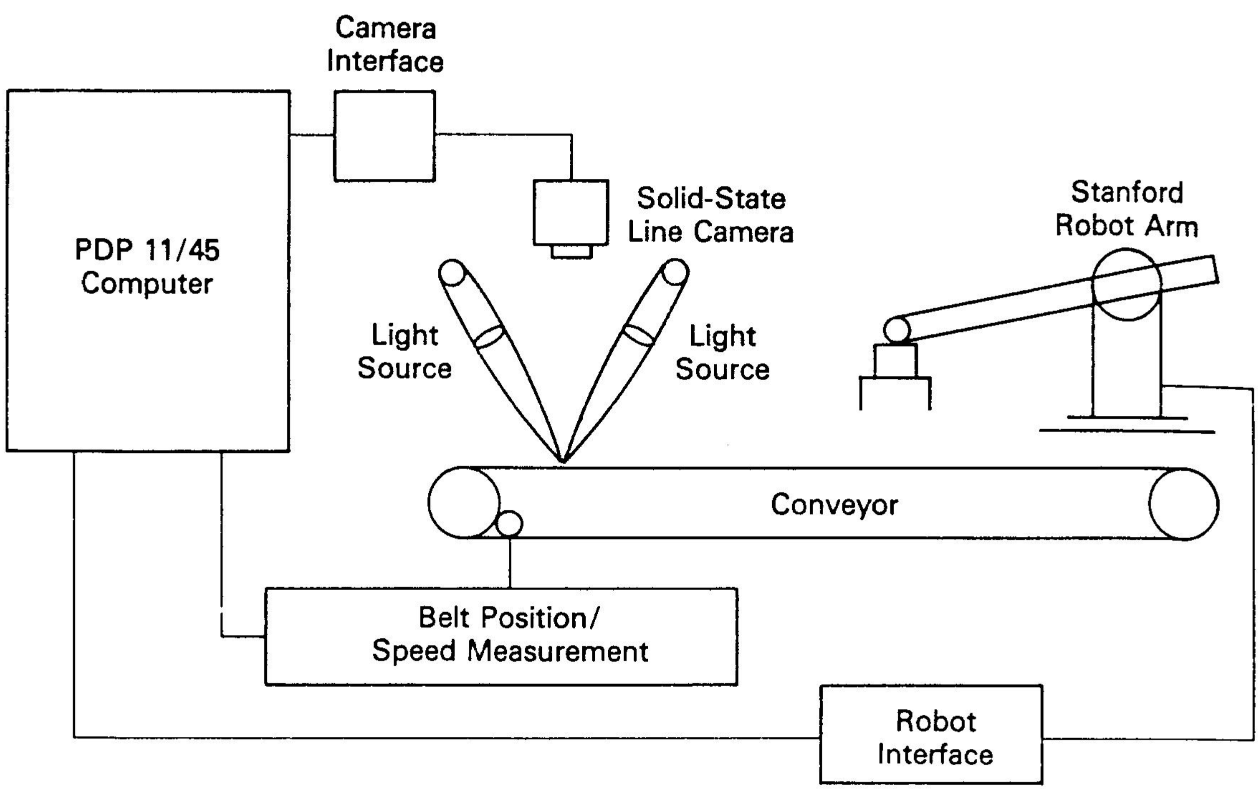
Example: A camera with a focal length f = 5cm is located 30cm to the right of a spot-scanning projector. A beam of light is projected at an angle of 45 degrees onto an object & reflected into the camera. Calculate the range of the point if it produces an image point located 2cm to the right of the image center.

5.5.5 Structure sensing:

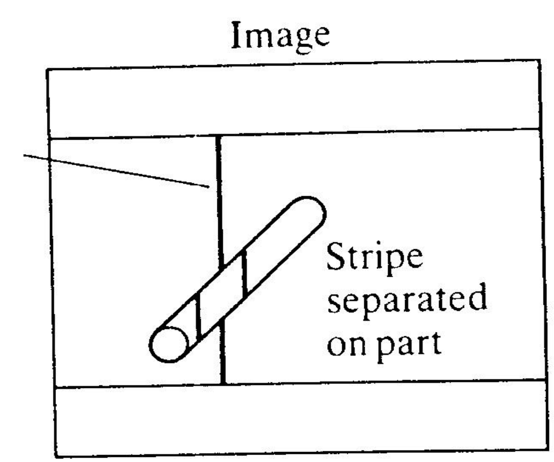
- It is an extension of spot sensing by project a stripe of light.
- The light stripe can be formed by passing ambient or infrared light through *a narrow slit* on the project.
- A laser stripe can be formed by *scanning the laser beam* rapidly in one plane or passing it through *a cylindrical lens*.
- The advantage of light striping: it is relative simple and fast.
- Light striping aids in the image-segmentation, i.e. finding object boundaries and regions.

5.5.5 Structure Sensing

***Application 1*: GM Consight I system**



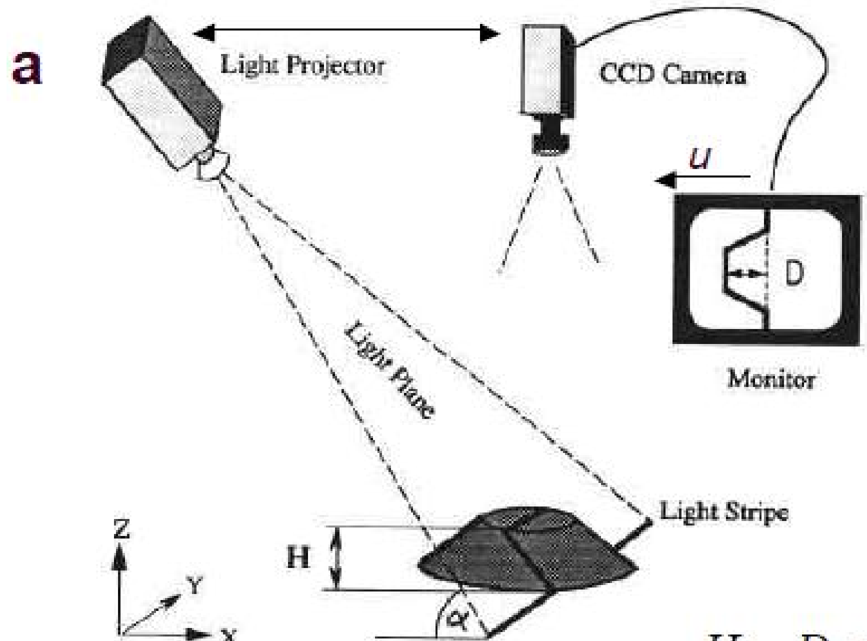
(a) System configuration



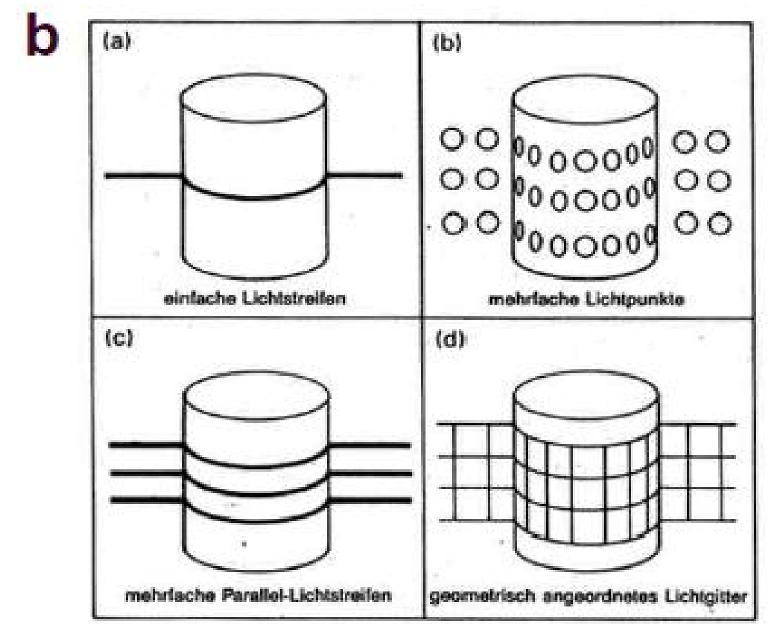
(b) Image

5.5.5 Structure Sensing

Application 2:



$$H = D \cdot tan\alpha$$



- Eliminate the correspondence problem by projecting structured li ght on the scene.
- Slits of light or emit collimated light (possibly laser) by mean s of a rotating mirror.
- Light perceived by camera
- Range to an illuminated point can then be determined from simple geometry.

5.5.5 Structure Sensing

5.6 Summary

- External sensors have three main functions:
  - -- to locate the robot with respect to the environment in order to travel around and implement a specific task.
  - -- to locate objects in the environment with respect to the robot in order to handle them and avoid collision.
  - -- to provide real data to update maps within the robotic systems for path planning and environment learning.
- Tactile sensing is relatively simple & economic, providing contact information.
- Proximity sensors are based on two main principles:
  - -- modification of an emitted optical signal
  - -- disturbance in the environment
- Range finding sensors are widely used in robotic systems for
  - -- detecting objects in the robot surrounding area for collision avoidance
  - -- providing information for a robot to build environment maps
  - -- locating objects for a robot to do manipulation