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MEng. ROBOTICS AND CONTROL SYSTEMS

(MRE002A) PERCEPTION

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1

INTRODUCTION

SENSORS II

SENSORS: RANGE SENSORS

- Range sensors

  - Sonar

  - Laser range finder

  - Time of Flight Camera

  - Structured light

SENSORS: RANGE TOF

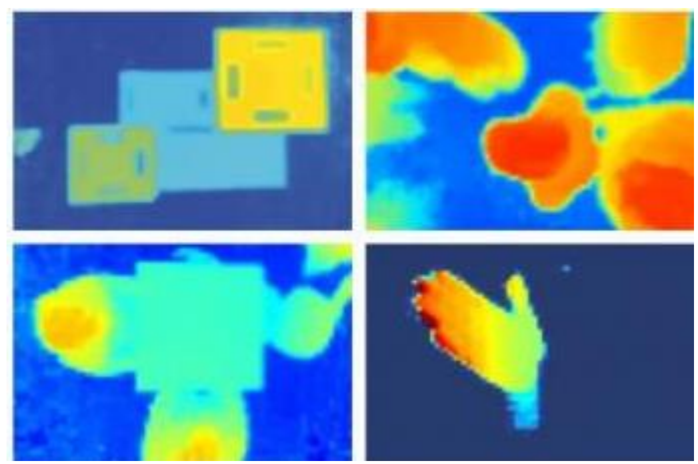
- Large range distance measurement -> thus called range sensors
  - Range information:
  - Key element for localization and environment modelling

- Ultrasonic sensors as well as laser range sensors make use of propagation speed of sound or electromagnetic waves respectively.

- The travelled distance of a sound or electromagnetic wave is given by

$$d = c \cdot t$$

  - d = distance travelled (usually round-trip)
  - c = speed of wave propagation
  - t = time of flight.



SENSORS: RANGE TOF

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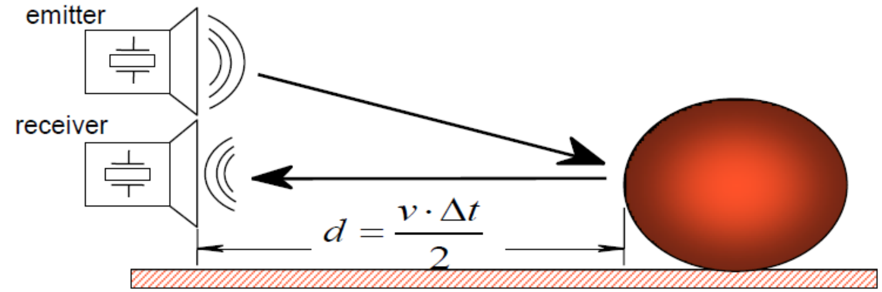
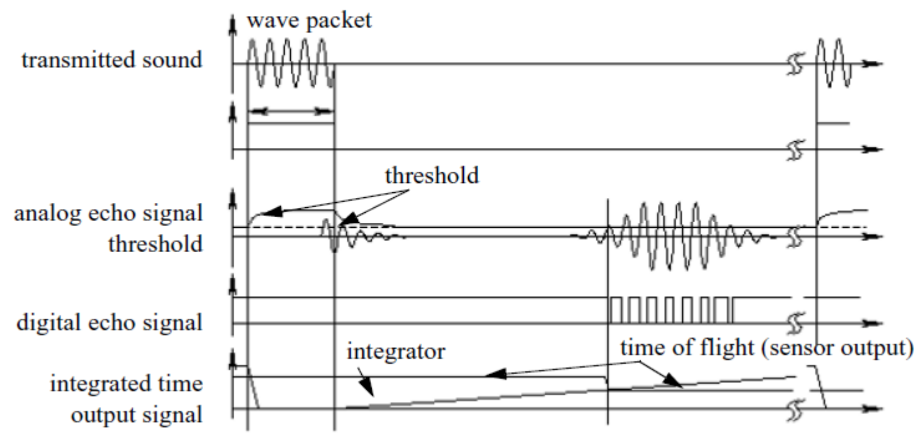
- It is important to point out
  - **Propagation speed of sound: 0.3 m/ms**
  - **Propagation speed of of electromagnetic signals: 0.3 m/ns,**
- **Electromagnetic signals travel one million times faster.**
- 3 meters
  - Equivalent to **10 ms** for an ultrasonic system
  - Equivalent to only **10 ns** for a laser range sensor
- Measuring time of flight with electromagnetic signals is not an easy task
- Laser range sensors expensive and delicate
- The quality of time of flight range sensors mainly depends on:
  - **Inaccuracies** in the time of fight **measurement** (laser range sensors)
  - **Opening angle** of transmitted beam (especially ultrasonic range sensors)
  - Interaction with the target (surface, specular reflections)
  - **Variation of propagation speed (sound)**
  - **Speed of mobile robot and target (if not at stand still)**

SENSORS: ULTRASONIC RANGE SENSOR

- Operational Principle
  - An ultrasonic pulse is generated by a piezo-electric emitter, reflected by an object in its path, and sensed by a piezo-electric receiver.
  - Based on the speed of sound in air and the elapsed time from emission to reception, the distance between the sensor and the object is easily calculated.



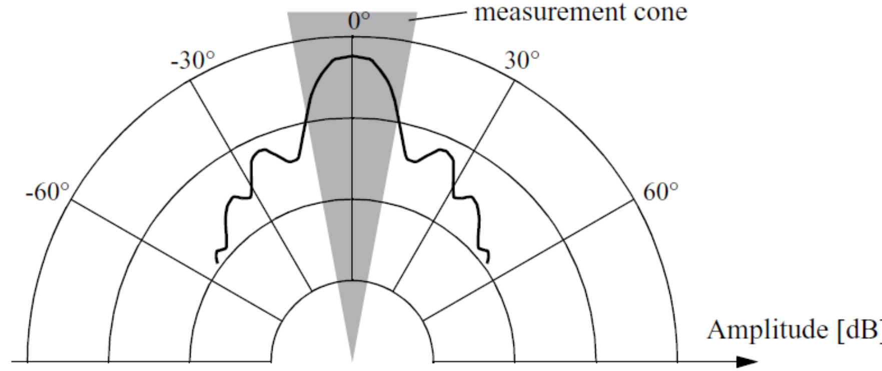


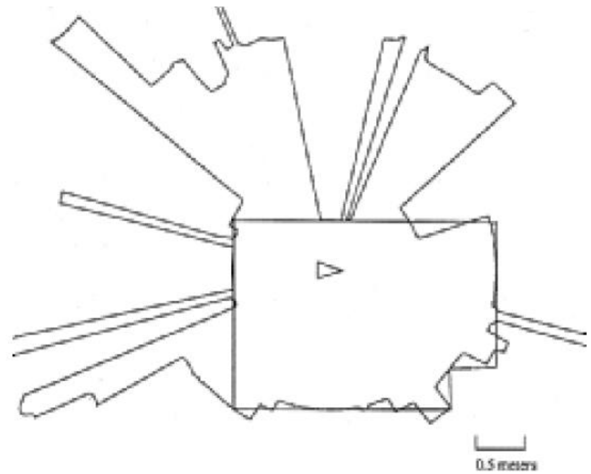
- Main Characteristics
  - Precision influenced by angle to object (as illustrated on the next slide)
  - Useful in ranges from several cm to several meters
  - Typically relatively inexpensive

- Applications
  - Distance measurement (also for transparent surfaces)
  - Collision detection

SENSORS: ULTRASONIC RANGE SENSOR

- Typical frequency: 40kHz - 180 kHz
  - Lower frequencies correspond to longer maximal sensor range
- Generation of sound wave via piezo transducer
  - Transmitter and receiver can be separate or integrated in the same unit
- **Range between 12 cm up to 5 m**
- **Resolution of ~ 2 cm**
- Relative error 2%
- Sound beam propagates in a cone (*approx*.)
  - **opening angles around 20 to 40 degrees**
  - regions of constant depth
  - segments of an arc (sphere for 3D)

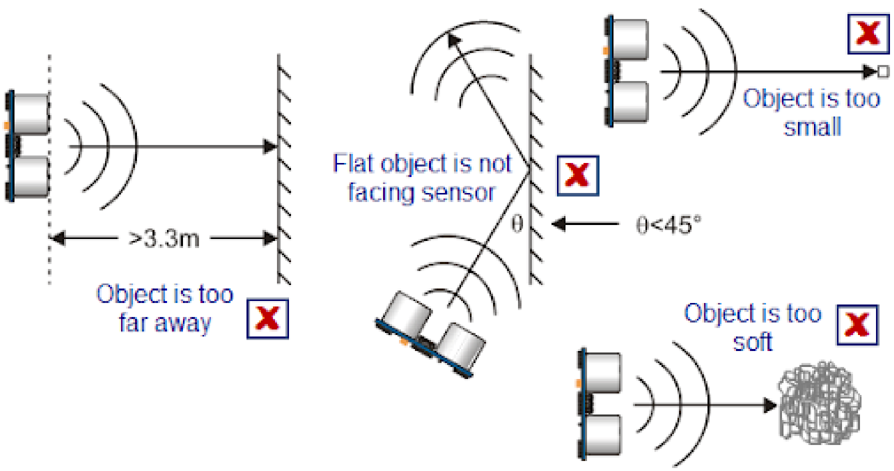


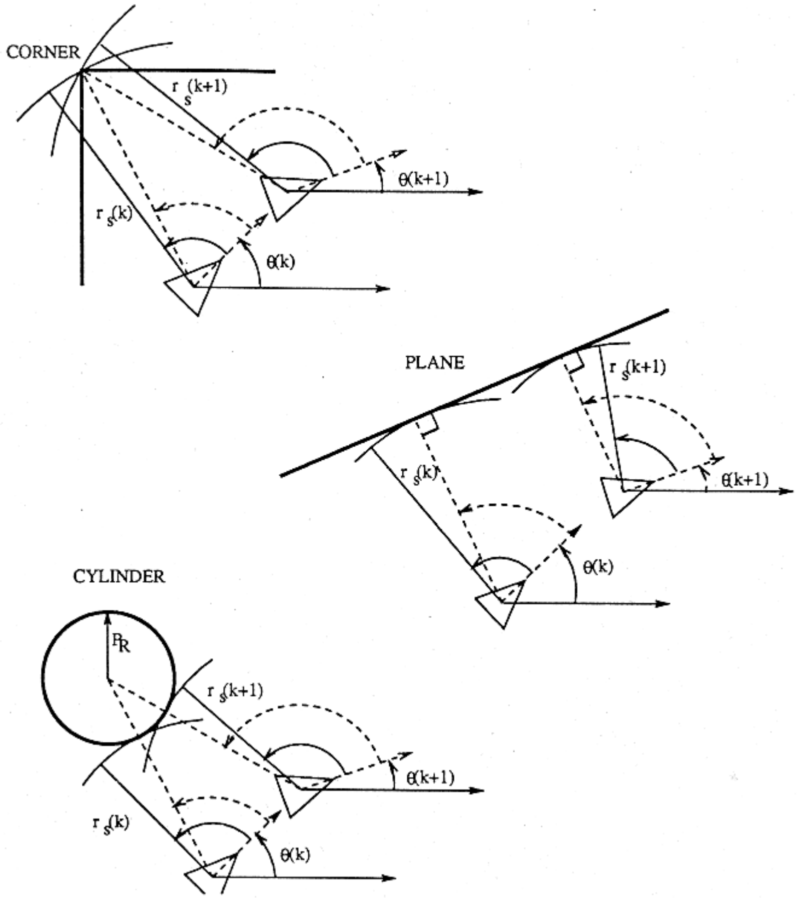


Typical readings of an ultrasonic system

SENSORS: ULTRASONIC RANGE SENSOR

- Other problems for ultrasonic sensors
  - Soft surfaces that **absorb** most of the sound energy
  - Surfaces that are fare from being perpendicular to the direction of the sound -> **Specular reflections**

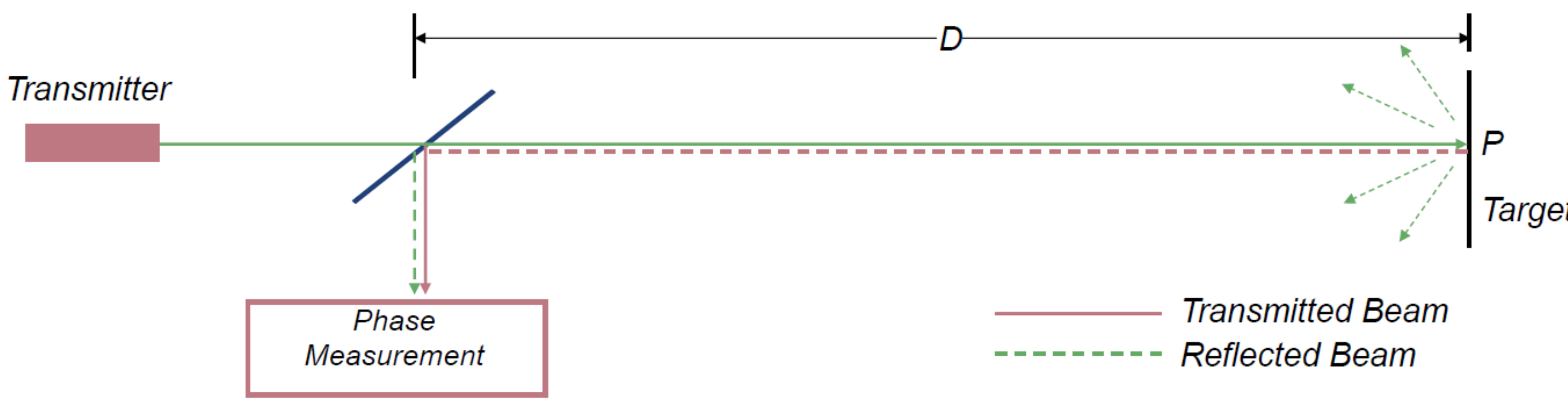




Results from different geometric primitives

SENSORS: LASER RANGE (LIDAR)

- Laser range finder are also known as **Lidar** (Light Detection And Ranging)
- Transmitted and received beams coaxial
  - Transmitter illuminates a target with a collimated laser beam
  - Receiver detects the time needed for round-trip
  - A mechanical mechanism with a mirror sweeps
- 2D or 3D measurement



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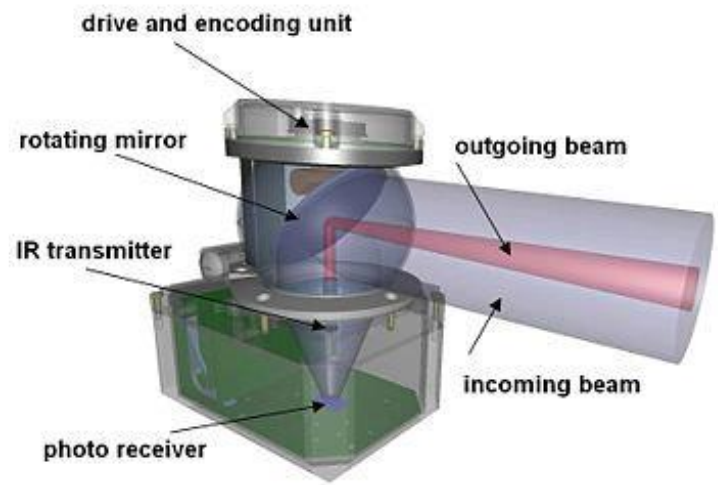
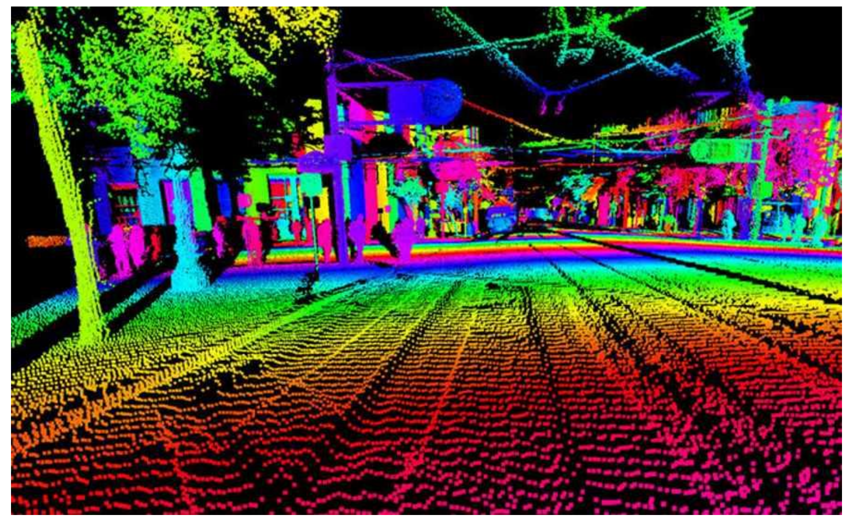




SENSORS: LASER RANGE (LIDAR)

- The sensor transmits 100% amplitude modulated light at a known frequency and measures the phase shift between the transmitted and reflected signals

- Wavelength λ of the modulated signals obeys the equation:

$$c = f \cdot \lambda$$

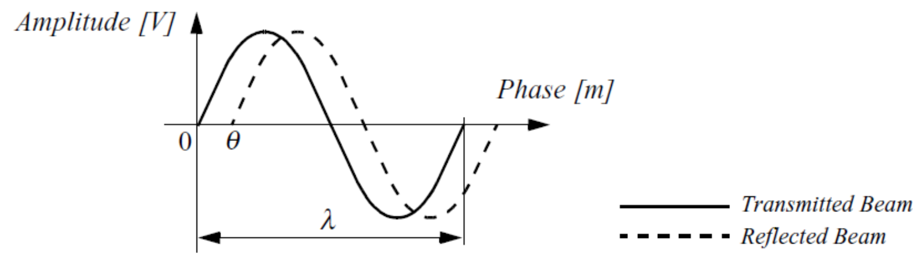
  c is the speed of light
  f is the modulating frequency

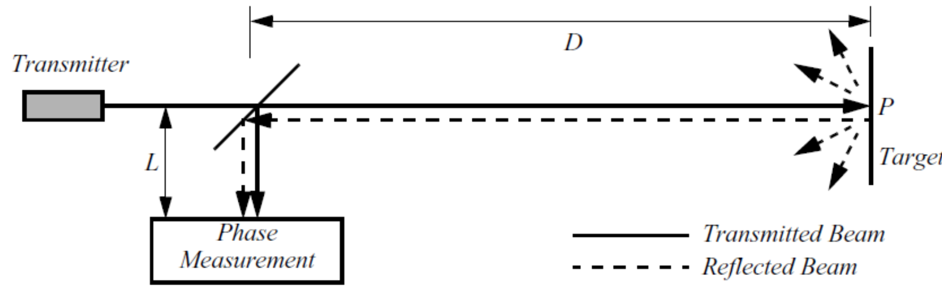
- For $f = 5\,MHz$ and $\lambda = 60\,m$. The total distance covered by the emitted light is:

$$D' = L + 2D = L + \frac{\theta}{2\pi}\lambda$$

$$D = \frac{\lambda}{4\pi}\theta$$

- E.g. if f = 5Mhz (i.e., λ = 60 meters) ⇒ max distance = 30 m ⇒ a target at a range of 35 meters = target at 5 meters





D and L are the distances defined in the figure

θ is the electronically measured phase difference between the transmitted and reflected light beams

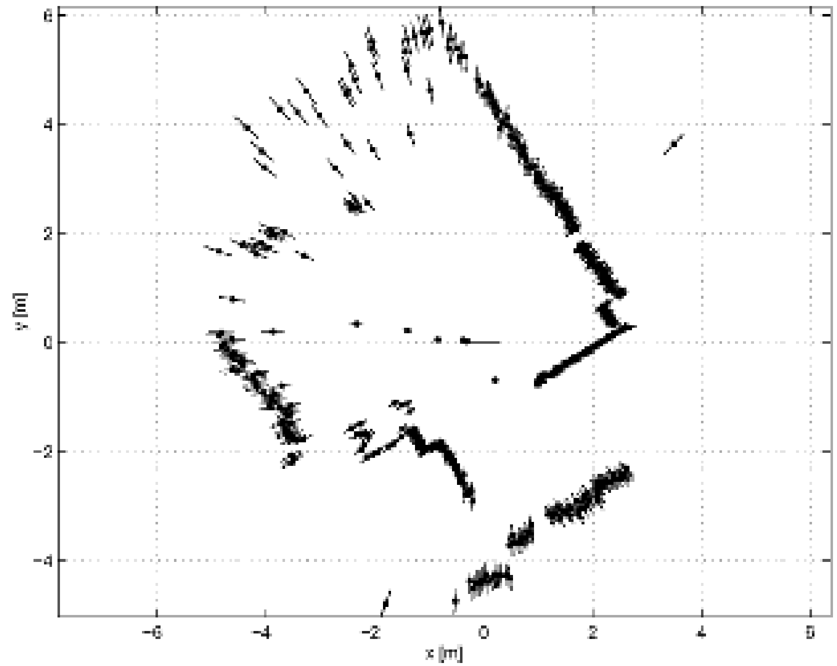
Max measurable distance = $\boldsymbol{\lambda}/2$ ⇒ ambiguous range estimates

SENSORS: LASER RANGE (LIDAR)

- Uncertainty of the range (phase/time estimate) is inversely proportional to the square of the received signal amplitude.

- Hence dark, distant objects will not produce such good range estimated as closer brighter objects.

Typical range image of a 2D laser range sensor with a rotating mirror. The length of the lines through the measurement points indicate the uncertainties.



SENSORS: TRIANGULATION SENSOR (1D)

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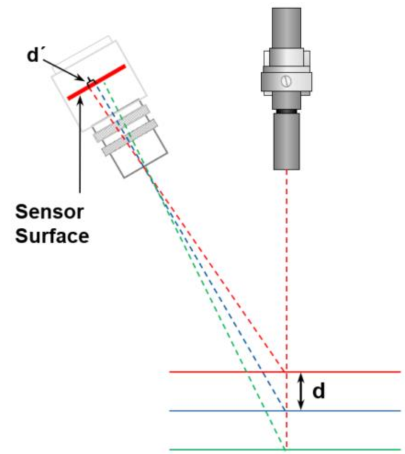
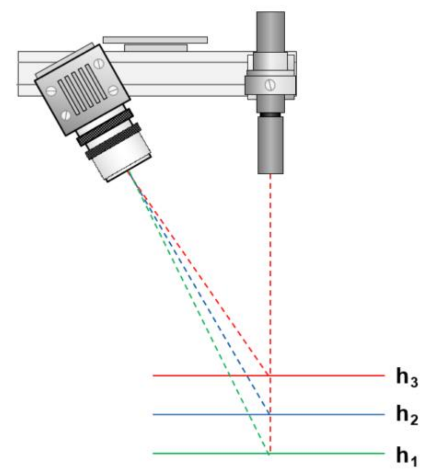
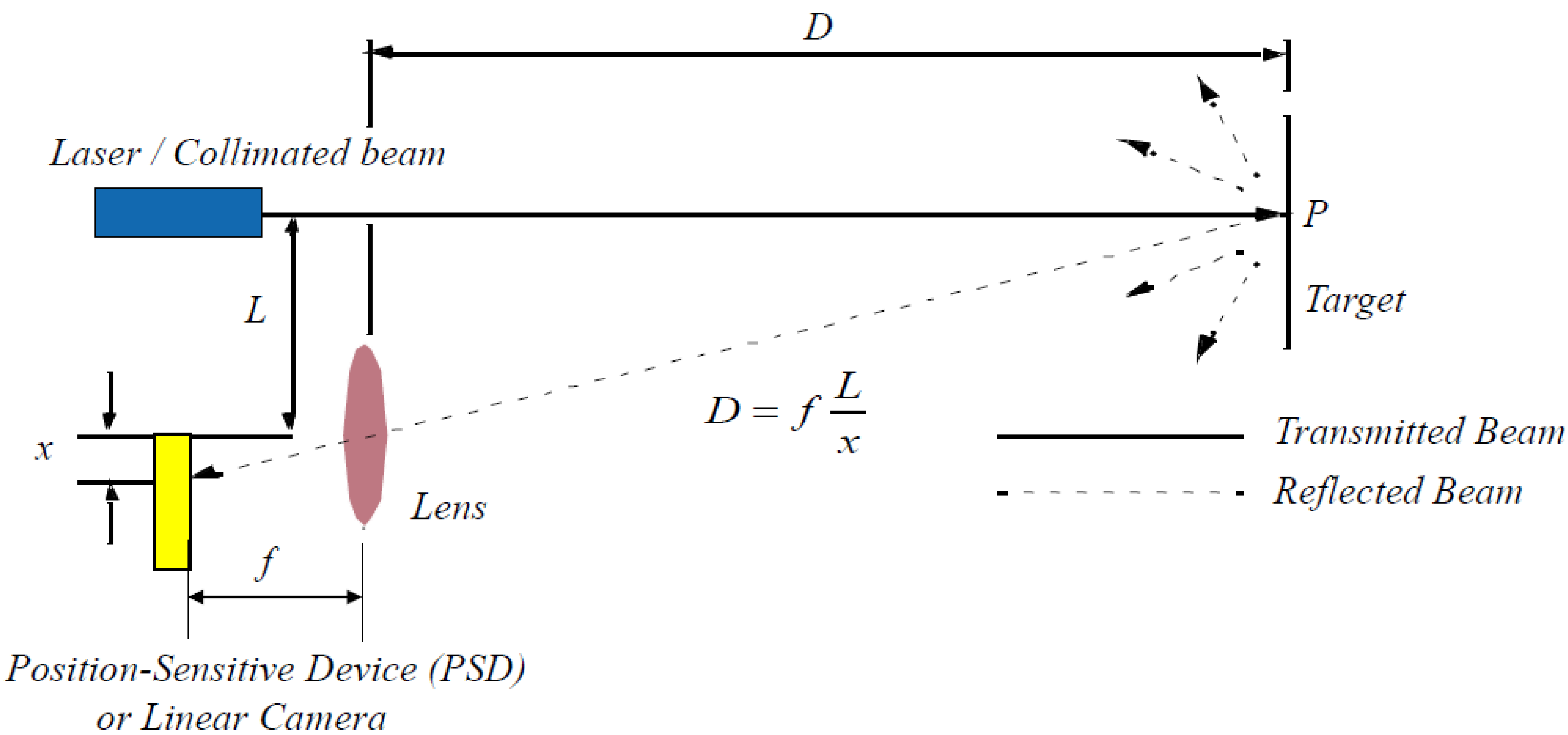
- Use of **geometrical properties** of the image to establish a **distance measurement**
- If a well defined light pattern (e.g. point, line) is projected onto the environment.
  - Reflected light is then captured by a photo-sensitive line or matrix (camera) sensor device
  - Simple triangulation allows us to establish a distance.
- If size of a captured object is precisely known
  - triangulation without light projecting





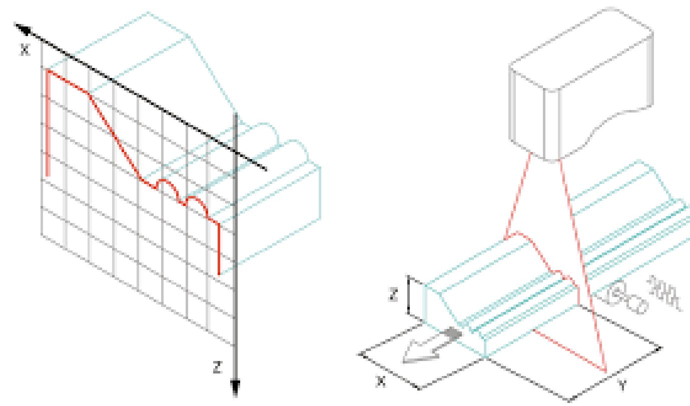
SENSORS: TRIANGULATION SENSOR (1D)

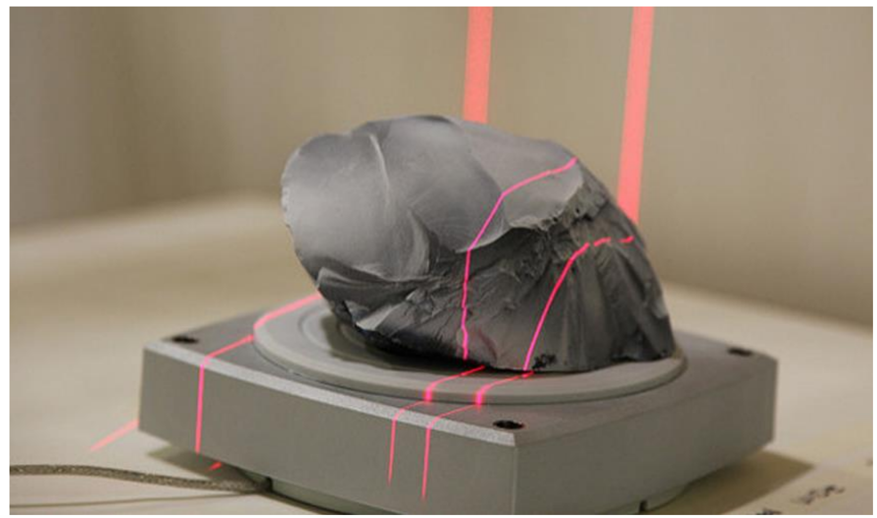
- Principle of 1D laser triangulation.



SENSORS: STRUCTURED-LIGHT (2D-3D)

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





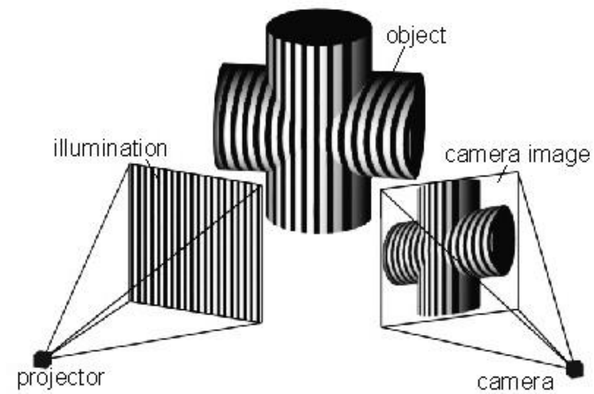
SENSORS: STRUCTURED-LIGHT (2D-3D)

- The *projection method* uses incoherent light and basically works like a video projector.

- Patterns are usually generated by passing light through a digital spatial light modulator, typically based on one of the three currently most widespread digital projection technologies.

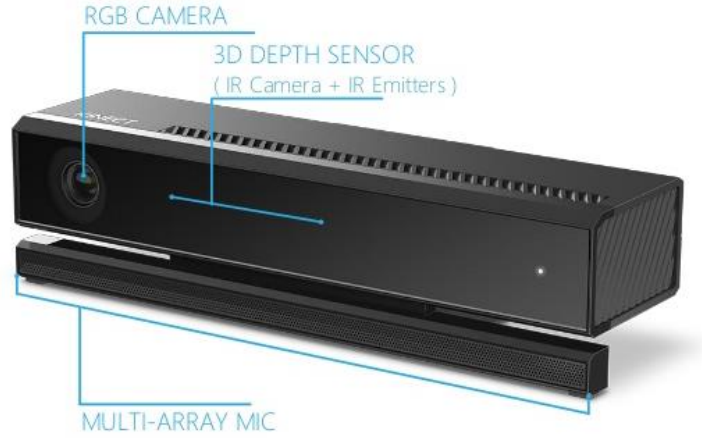
- As with all optical methods, reflective or transparent surfaces raise difficulties.
  - Reflections cause light to be reflected either away from the camera or right into its optics.

- Transparent or semi-transparent surfaces also cause major difficulties. Alternative optical techniques have been proposed for handling perfectly transparent and specular objects.



SENSORS: STRUCTURED-LIGHT (2D-3D)

- Microsoft Kinect
  - Major components
    - IR Projector
    - IR Camera
    - VGA Camera
    - Microphone Array
  - Motorized Tilt
  - Field of view: 57.5º X – 43.5º Y
  - Camera resolution: 1920x1080 px



SENSORS: Depth Computation I

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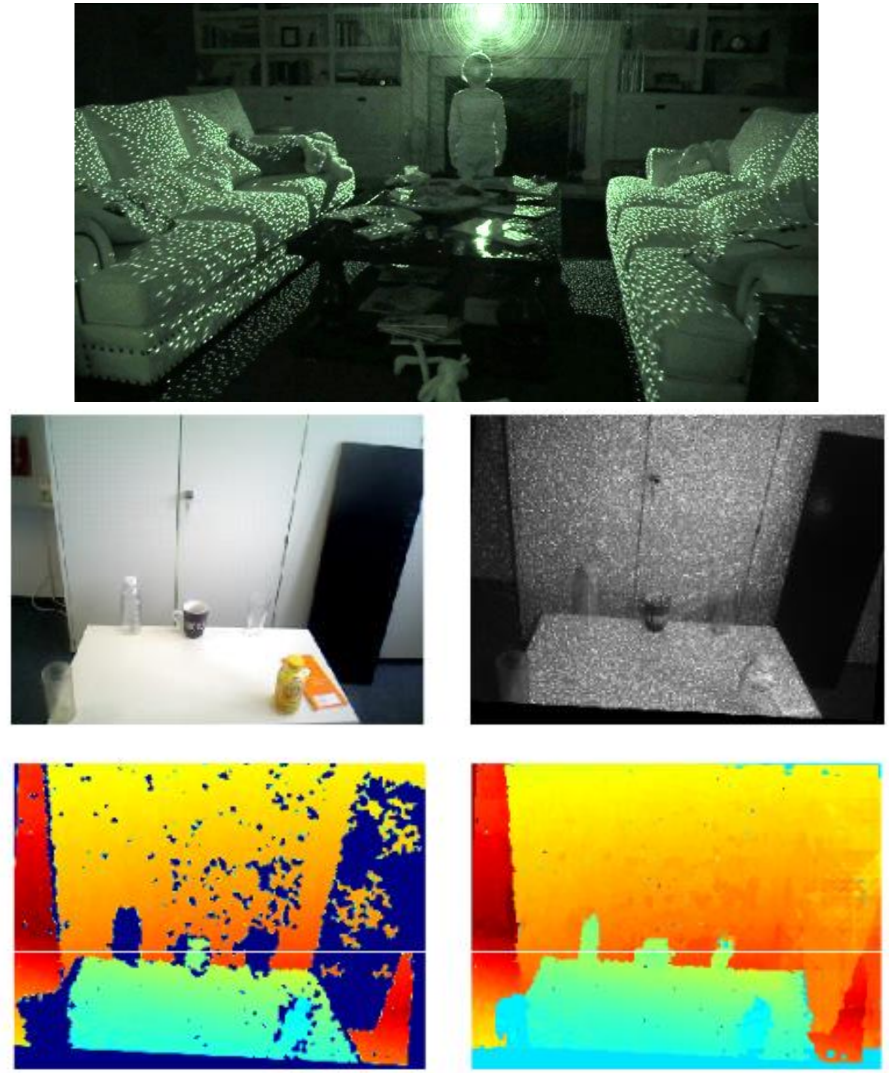
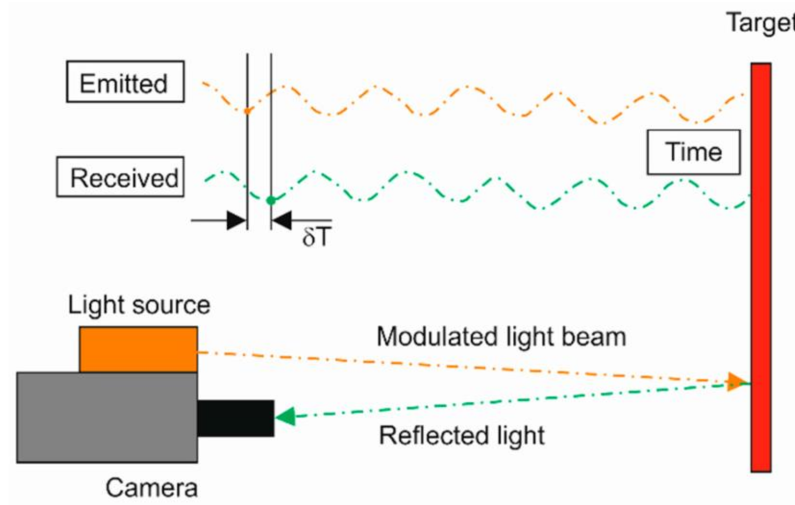
- Depth from Stereo
- The Kinect uses an infrared projector and an infrared sensor; it does not use its RGB camera for depth computation
- The technique of analysing a known pattern is “structured light”
- The IR projector projects a pseudo-random pattern across the surface of the room.
- The direction of each speckle of the patter is known (from pre calibration during manufacturing) and is hardcoded into the memory of the Kinect
- By measuring the position of each speckle in the IR image, its depth can be computed

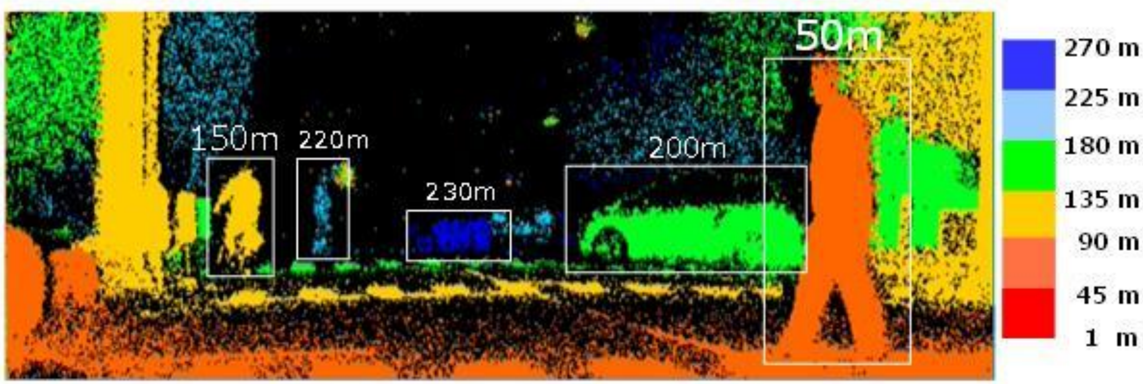


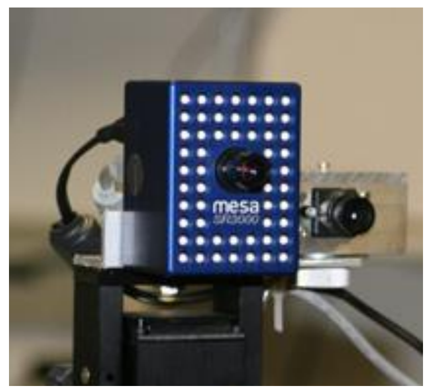
SENSORS: Time Of Flight (TOF)

- A Time-of-Flight camera (TOF camera, figure) works similarly to a lidar with the advantage that **the whole 3D scene is captured at the same time and that there are no moving parts.**

- This device uses an infrared lighting source to determine the distance for each pixel of a Photonic Mixer Device (PMD) sensor.







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THANK YOU

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