Distance Sensors: Sound, Light and Vision

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SEMINAR: INTELLIGENT ROBOTICS

Structure

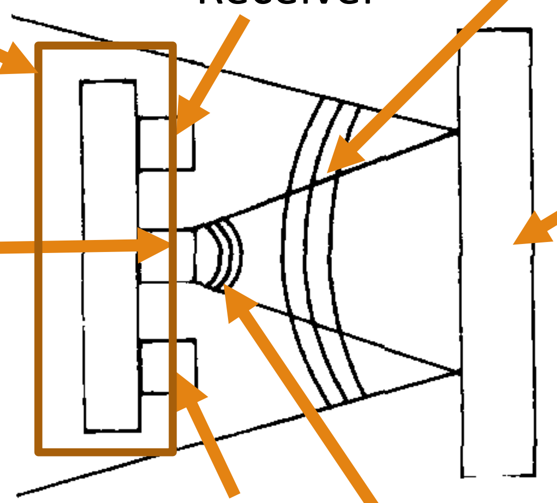
- Motivation
- Distance Sensors
  - Sound
  - Light
  - Vision
- Common Applications
- Limitations
- Conclusion
- Sources

Motivation

- Distance-Sensors
  - Used in Cars
    - Parking assistant
    - Autonomous driving
  - Used by different Robots
    - To detect obstacles and avoid crashes

Distance Sensors - Sound

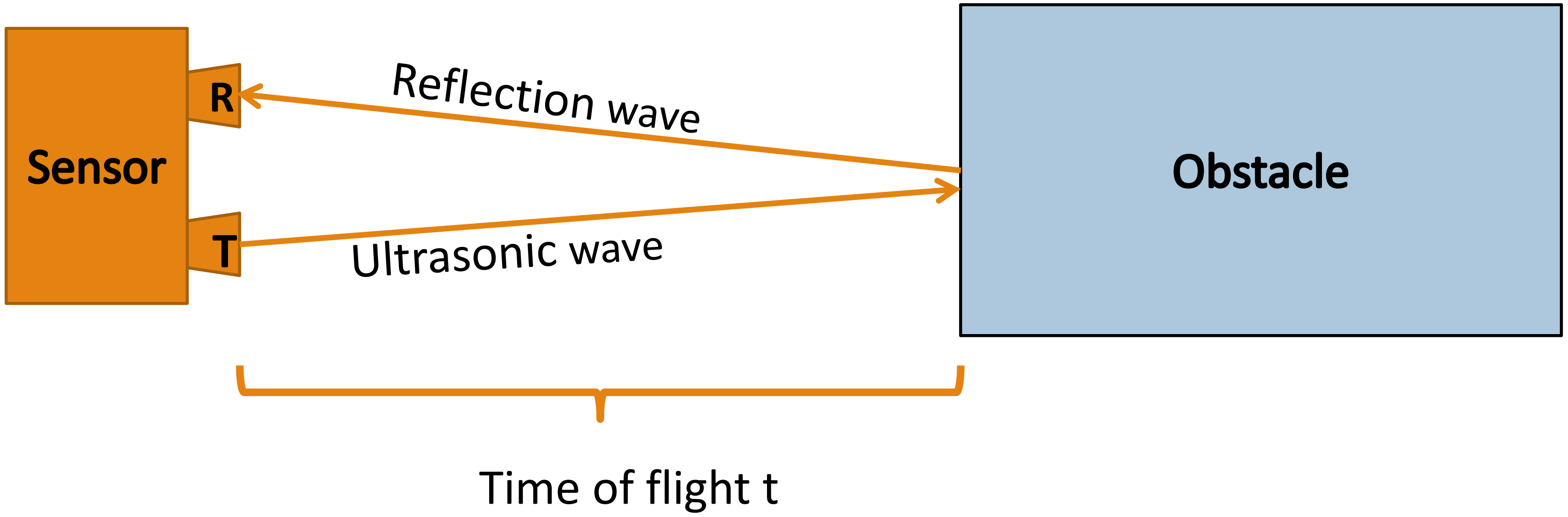
- Ultrasonic sensor



Source: [1]

Distance Sensors - Sound

- Time of Flight measurement
  - Time between transmission and detection
  - Distance $D = \frac{t}{2}c$ (c is velocity, approx. 340 m/s)

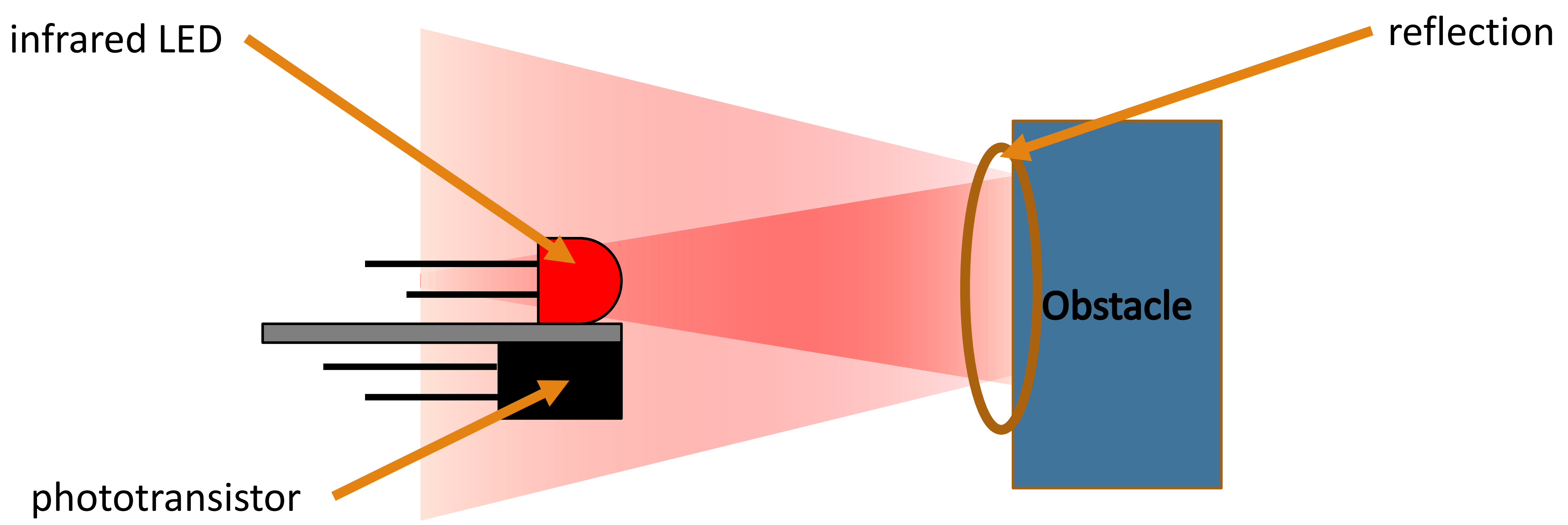


Distance Sensors - Sound

- low sensitivity to environmental conditions
  - Speed of sound depends on temperature
    - +0.17% / °C ⇔ 0.578m/s / °C
  - Can operate in dusty and dirty environments
- Measurement range 0-2.5 Meters with precision of 3cm

Distance Sensors - Light

- Infrared sensor



Distance Sensors - Light

- Three steps for Measuring Distance

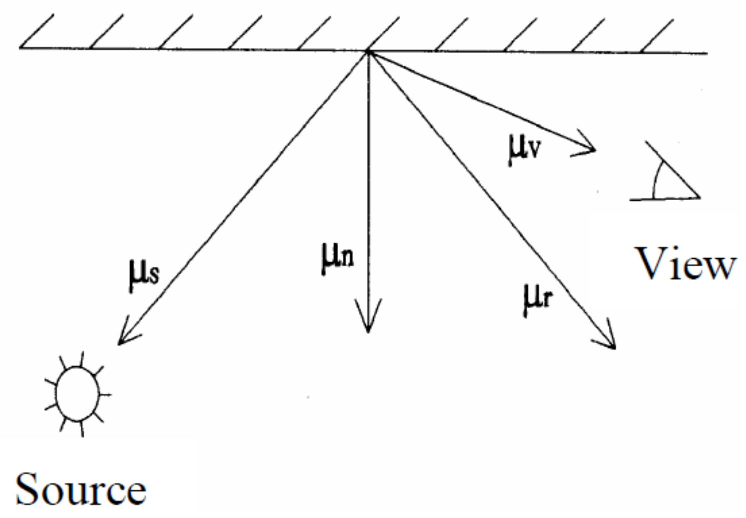
1. Determine reflecting properties of obstacles
2. Determine angle of obstacle relative to the sensor
3. Compute the distance using informations of step 1 and 2

Distance Sensors - Light

- Determine reflecting properties of obstacles
- Phong Modell
  - Surfaces scatter, absorb and reflect light in different portions
  - Simplification of these effects
  - Intensity of reflection $I = C_0(\overrightarrow{\mu_s} \cdot \overrightarrow{\mu_n}) + C_1(\overrightarrow{\mu_r} \cdot \overrightarrow{\mu_v})^n + C_2$

Distance Sensors - Light

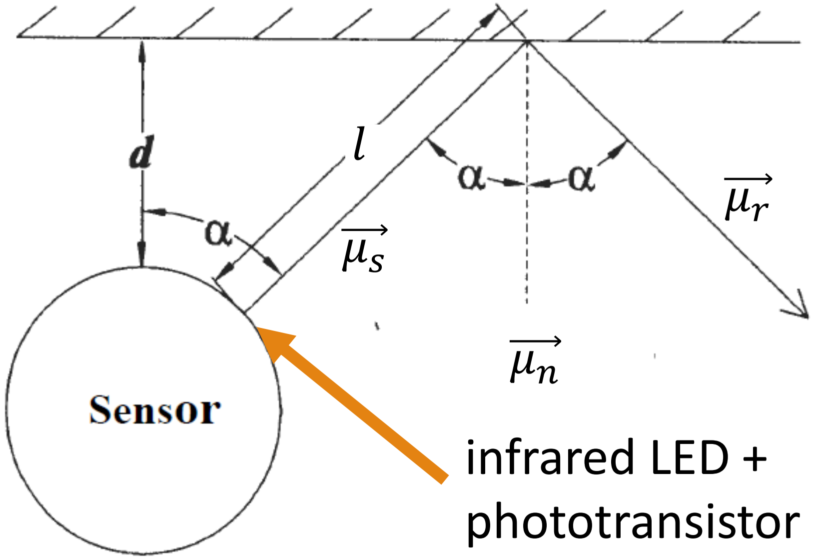
- Intensity of reflection $I = C_0(\overrightarrow{\mu_s} \cdot \overrightarrow{\mu_n}) + C_1(\overrightarrow{\mu_r} \cdot \overrightarrow{\mu_v})^n + C_2$
  - Four constants C_0, C_1, C_2 and n
  - Four vectors
    - Light source: $\overrightarrow{\mu_s}$
    - Normal vector: $\overrightarrow{\mu_n}$
    - Reflected light: $\overrightarrow{\mu_r}$
    - Viewing vector: $\overrightarrow{\mu_v}$



Source: [4]

Distance Sensors - Light

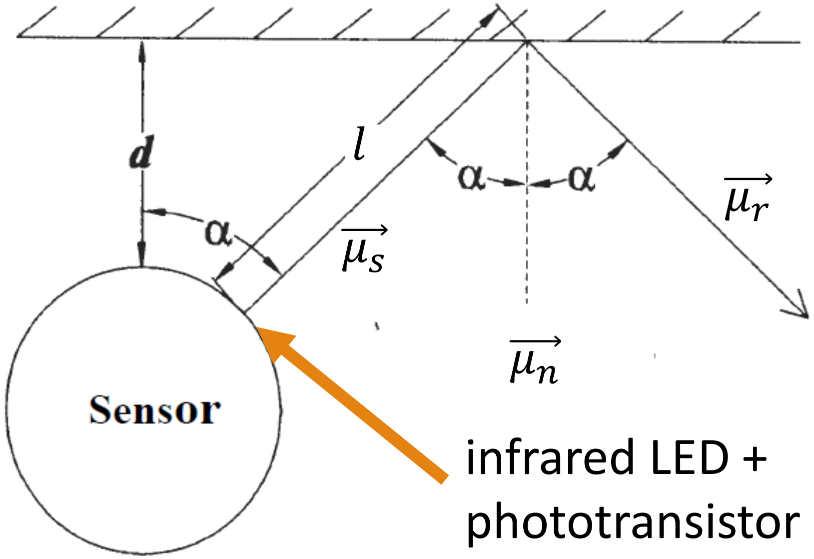
- Intensity of reflection $I = C_0(\overrightarrow{\mu_s} \cdot \overrightarrow{\mu_n}) + C_1(\overrightarrow{\mu_r} \cdot \overrightarrow{\mu_v})^n + C_2$
- Asume: reveiver and transmitter are in the same position
  - $\Rightarrow I = C_0 \cos(\alpha) + C_1 \cos^n(2\alpha) + C_2$
- Traveled distance $2l$
  - expressed in terms of d, α and radius of the sensor (r)
  - $l = \frac{d}{\cos(\alpha)} + r\left(\frac{1}{\cos(\alpha)} - 1\right)$



Source: [4]

Distance Sensors - Light

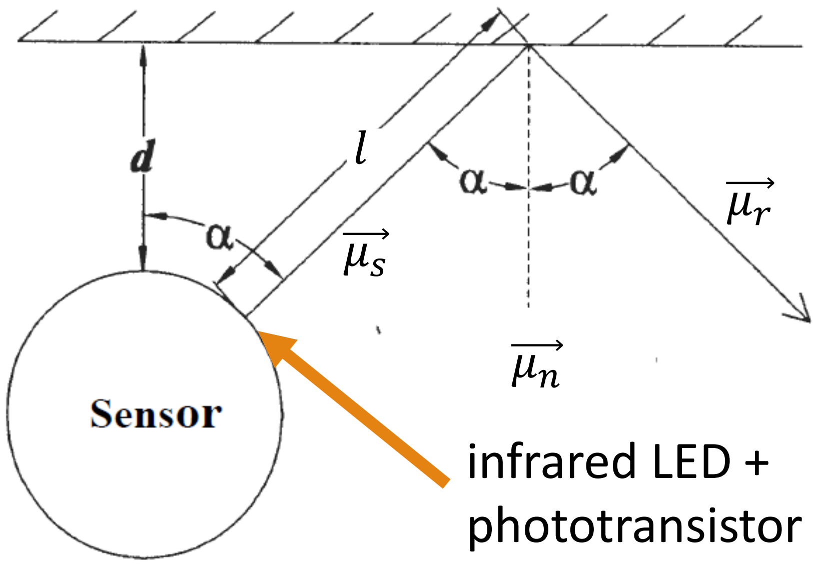
- Energy (E) absorbed by the phototransistor depends on
  - Intensity of reflection (I)
  - Traveled light distance $(2l)$
  - Area of the sensor (A)
- $E = \dfrac{IA}{(2l)^2}$



Source: [4]

Distance Sensors - Light

- $E = \frac{IA}{(2l)^2}$
- $I = C_0\cos(\alpha) + C_1 \cos^n(2\alpha) + C_2$
- $l = \frac{d}{\cos(\alpha)} + r\left(\frac{1}{\cos(\alpha)} - 1\right)$
- Assume that $C_2 = 0, n = 1$ and A is constant
- $\Rightarrow E = \frac{C_0 \cos(\alpha)+C_1 \cos(2\alpha)}{\left[\frac{d}{\cos(\alpha)}+r\left(\frac{1}{\cos(\alpha)}-1\right)\right]^2}$



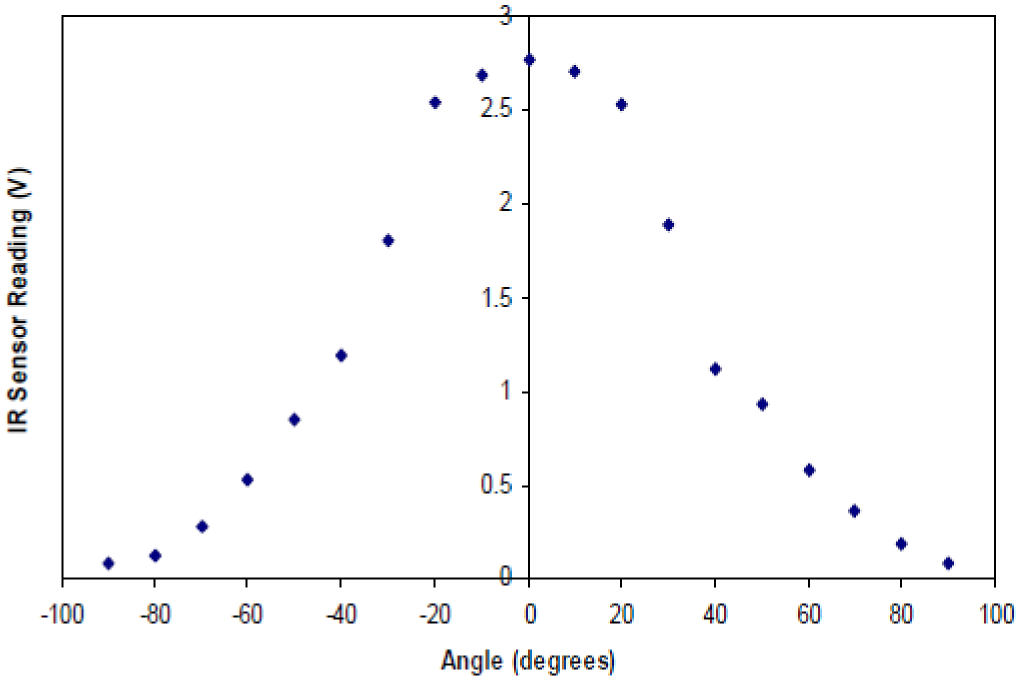
Source: [4]

Distance Sensors - Light

- $\Rightarrow E = \frac{C_0 \cos(\alpha) + C_1 \cos(2\alpha)}{\left[\frac{d}{\cos(\alpha)} + r\left(\frac{1}{\cos(\alpha)} - 1\right)\right]^2}$
- C_0 and C_1 indicate the infrared characteristics of an obstacle
- Determine by taking infrared reading at known distances (d) and angles (α)

Distance Sensors - Light

- Determine angle of obstacle relative to the sensor
  - Maximum reading E will occur at $\alpha = 0$



E.g. Data collected from a flat surface 10 cm from sensor at different angles

Source: [4]

Distance Sensors - Light

- Compute the distance using informations of step 1 and 2
- $E = \frac{C_0 \cos(\alpha) + C_1 \cos(2\alpha)}{\left[\frac{d}{\cos(\alpha)} + r\left(\frac{1}{\cos(\alpha)} - 1\right)\right]^2}$
- $\Leftrightarrow d = r(\cos(\alpha) - 1) + \cos(\alpha)\sqrt{\frac{C_0 \cos(\alpha) + C_1 \cos(2\alpha)}{E}}$

Distance Sensors - Light

- Faster response times than ultrasonic
- Dependence on the reflectance of surrounding objects
- Measurement range 5cm – 10m
- Precision less than 1cm (measurement range up to 6m)

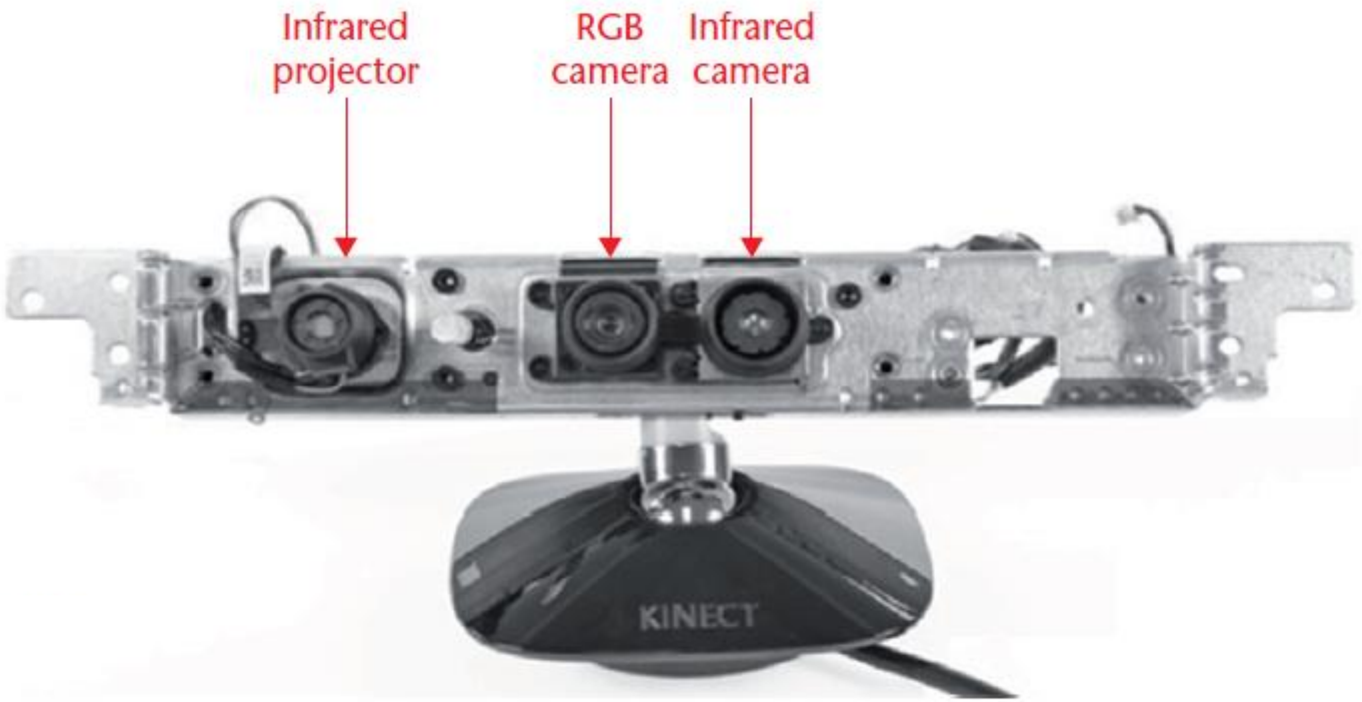
Distance Sensors - Vision

- Kinect 1
  - People are able to interact in a game with their body
  - Reconstructed a 3D Model of the environment
  - Interprets movements

Source: [IMG1]

Distance Sensors - Vision

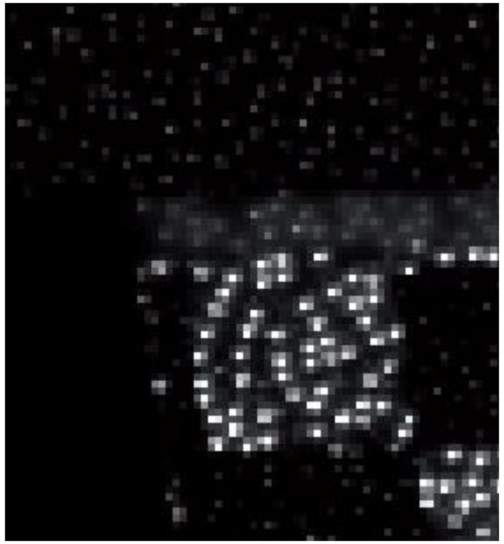
- Contains a RGB camera
- Depth sensor
  - Infrared projector
  - Infrared camera

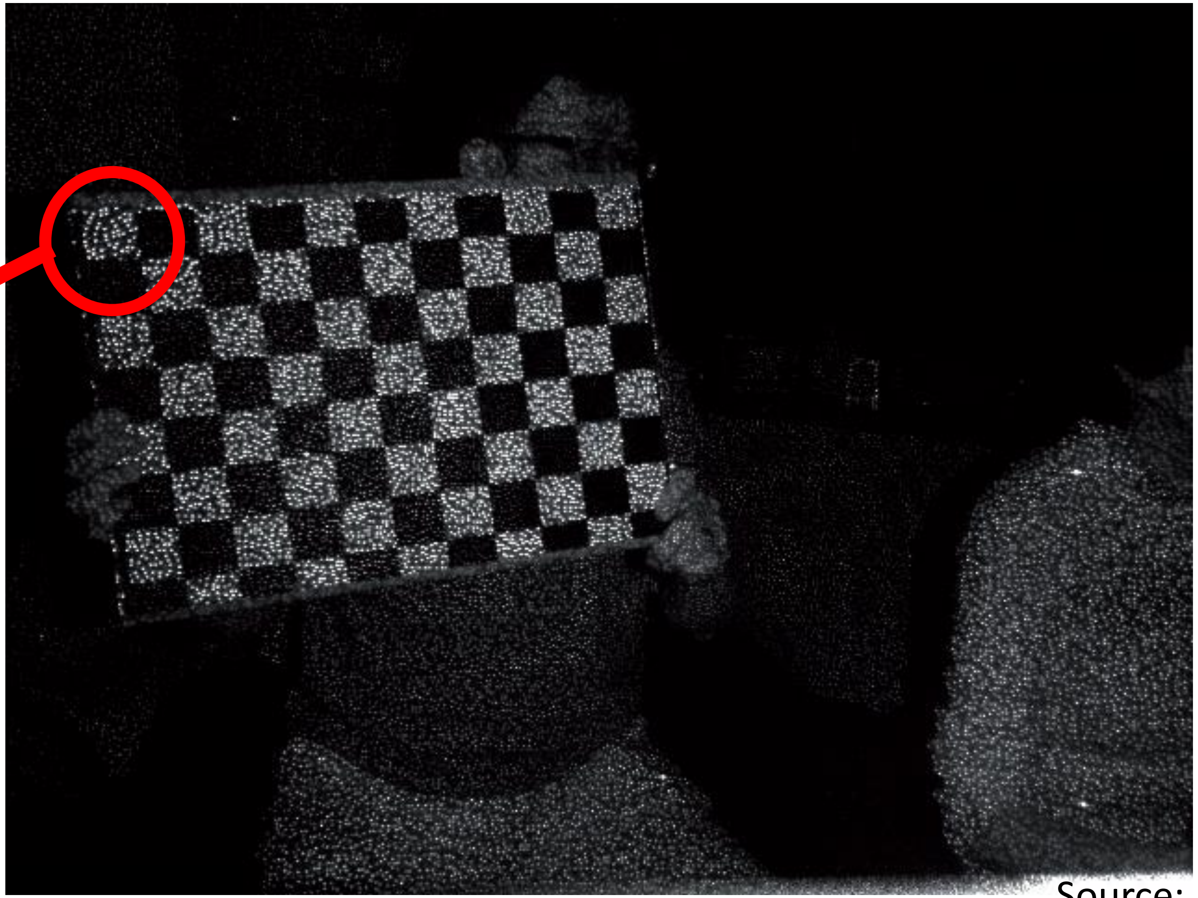


Source: [6]

Distance Sensors - Vision

- Technique of structured light

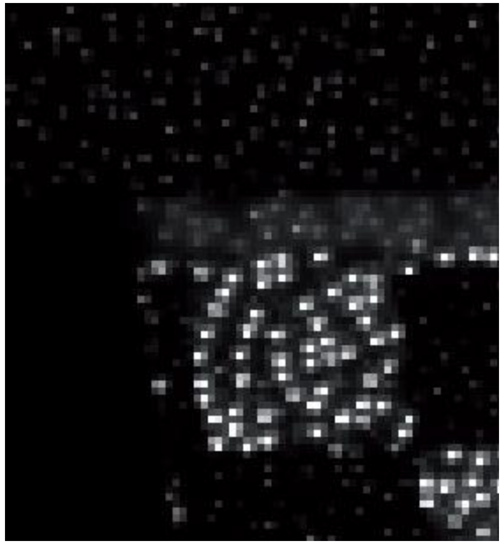




Source: [6]

Distance Sensors - Vision

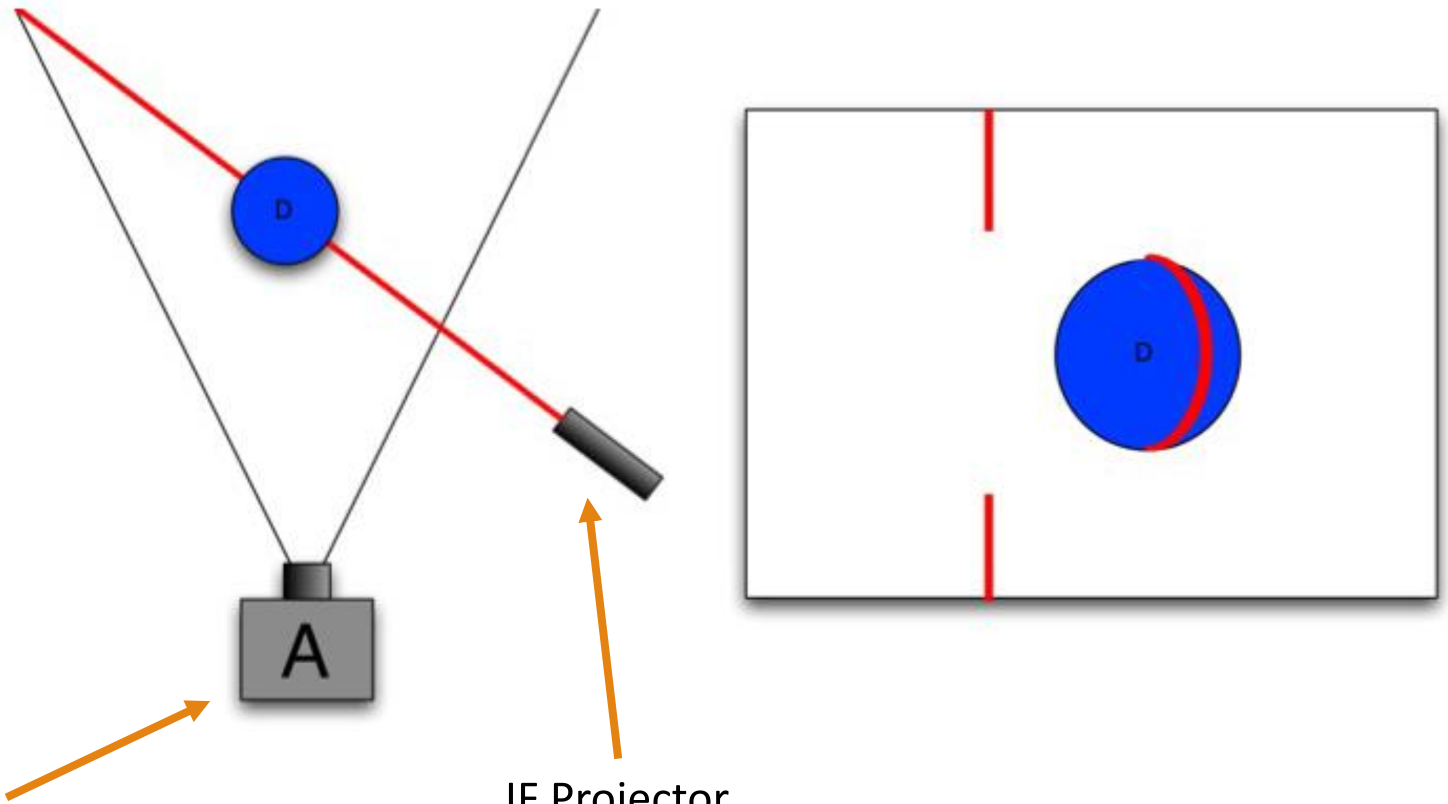
- Technique of structured light
- The sensor knows
  - Relative geometry between IR projector and IR camera
  - Dot pattern



Source: [6]

Distance Sensors - Vision

- A single frame



Source: [IMG4]

Distance Sensors - Vision

- Depth image

Source: [6]

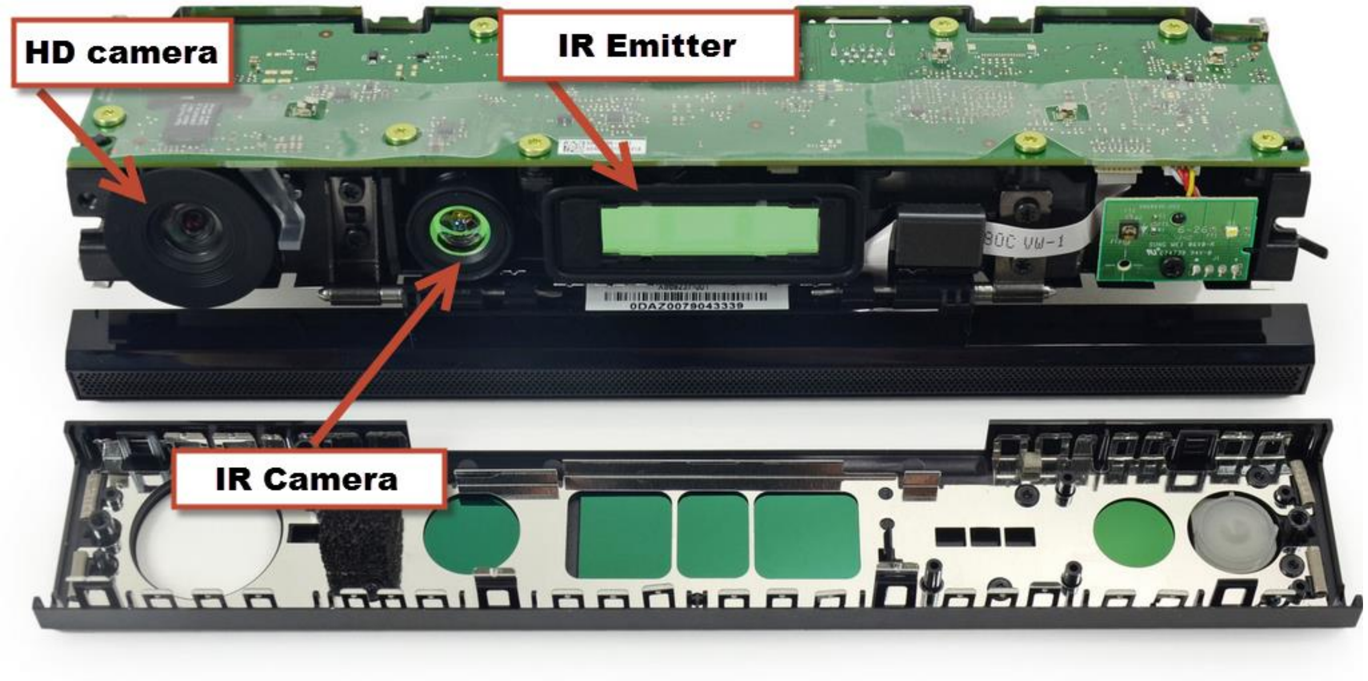
Distance Sensors - Vision

- Kinect 2

Source: [IMG2]

Distance Sensors - Vision

- Kinect 2
  - Uses Time of Flight



Source: [IMG3]

Distance Sensors - Vision

- Paranormal Activity
  - Kinect can see imaginary friends

Source: [IMG3]

Common Applications

- Ultrasonic sensors
  - Cars
  - Medicine
  - Underwater
- Infrared sensors
  - Night Vision Devices
  - Astronomy
- Kinect
  - Virtual Realitiy Interactions
  - 3D Scans

Limitations

- Ultrasonic sensors
  - Useless in space
  - requires a minimum target surface area
  - Targets of low density may be difficult to sense
- Infrared sensors
  - Needs clear area between sufrace and phototransistor
- Kinect
  - Similar to infrared
  - Cant use in dark environments

Conclusion

- Ultrasonic sensors
  - low sensitivity to environmental conditions
- Infrared sensors
  - Faster than ultrasonic sensors
  - Higher dependency on environment
  - Needs calibration
- Kinect
  - State-of-the-art
  - Used in gaming and for 3D-Scans
  - Is able to detect movements

Literature

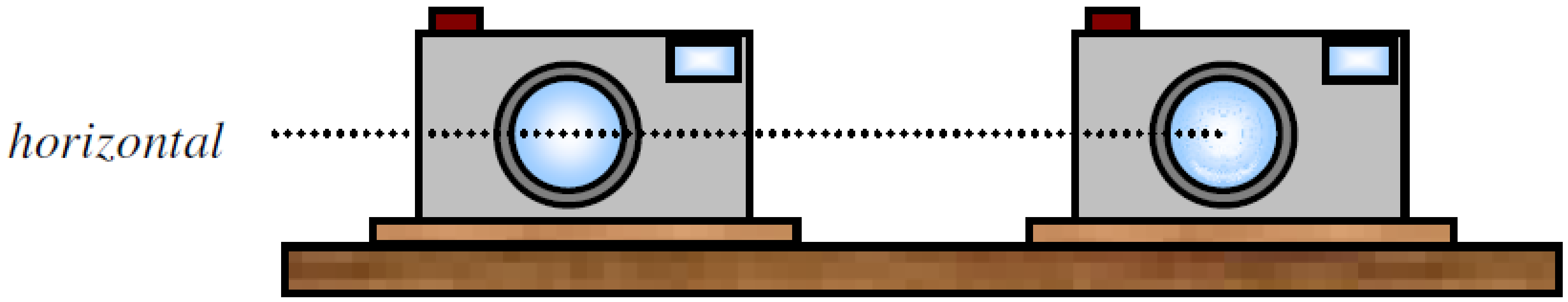
- [1] Title: Ultrasonic Distance Measurement for Linear and Angular Position Control, Author: Daniele Marioli, Emilio Sardini, Andrea Taroni, published by: IEEE Transactions on Instrumentation and Measurement. Vol. 37 No. 4, Dec 1988
- [2]Title: Ultrasonic Distance Measurement, Author: Ju Yangyan, published by: XX International conference for students and young scientists <<MODERN TECHNIQUE AND TECHNOLOGIES>>. Section 2
- [3]Title: Using infrared sensors for distance measurement in mobile robots, Author: G.Benet, F. Blanes, J.E. Simó, P. Pérez, published by Robotics and Autonomous Systems 1006 (2002) 1–12, Mar 2002
- [4]Title: Using Ultrasonic and Infrared Sensors for Distance Measurement, Author: Tarek Mohammad, published by: International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:3, No:3, 2009
- [5]Title: Distance measuring based on stereoscopic pictures, Author: Jernej Mrovlje, Damir Vrancic, published by 9th International PhD Workshop on Systems and Control: Young Generation Viewpoint, Oct 2003
- [6]Title: Microsoft Kinect Sensor and Its Effect, Author: Zhengyou Zhang, published by IEEE MultiMedia Volume 19, Apr 2012
- [7] http://www.ab.com/en/epub/catalogs/12772/6543185/12041221/12041229/Ultrasonic-Advantages-and-Disadvantages.html (09.11.2016)
- [8] http://www.hongkiat.com/blog/innovative-uses-kinect/ (09.11.2016)
- [9] http://www.azosensors.com/article.aspx?ArticleID=339 (09.11.2016)

Images/videos

- [IMG1] https://de.wikipedia.org/wiki/Kinect#/media/File:Xbox-360-Kinect-Standalone.png (09.11.2016)
- [IMG2] https://www.extremetech.com/wp-content/uploads/2013/09/Kinect-640x353.png (09.11.2016)
- [IMG3] https://social.msdn.microsoft.com/Forums/getfile/500812 (09.11.2016)
- [IMG4] http://lau.engineering.uky.edu/files/2013/11/Slide2.jpg (09.11.2016)
- [VID1] https://www.youtube.com/watch?v=kDgWm8xJ-As (09.11.2016)

Distance Sensors - Vision

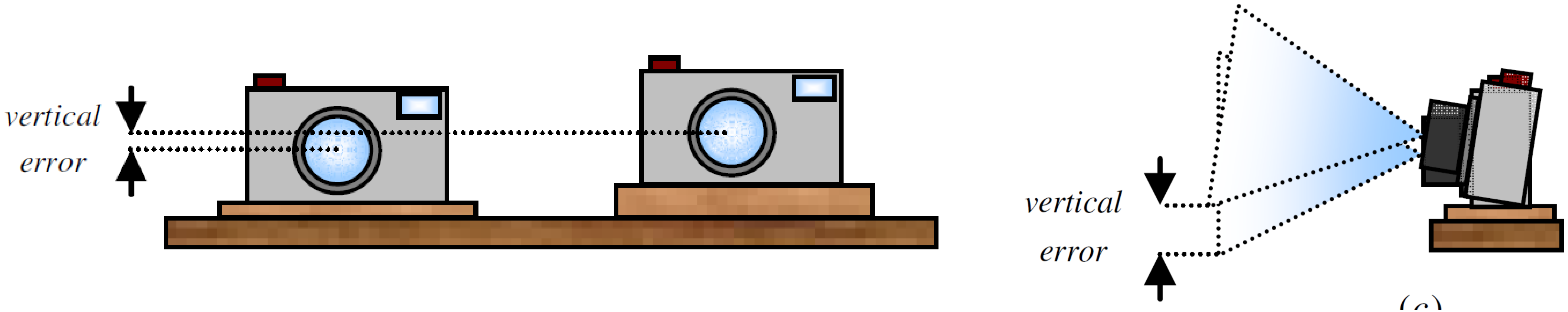
- Stereoscopy
  - Two cameras
  - Create an illusion of depth (3D Images)



Source: [5]

Distance Sensors - Vision

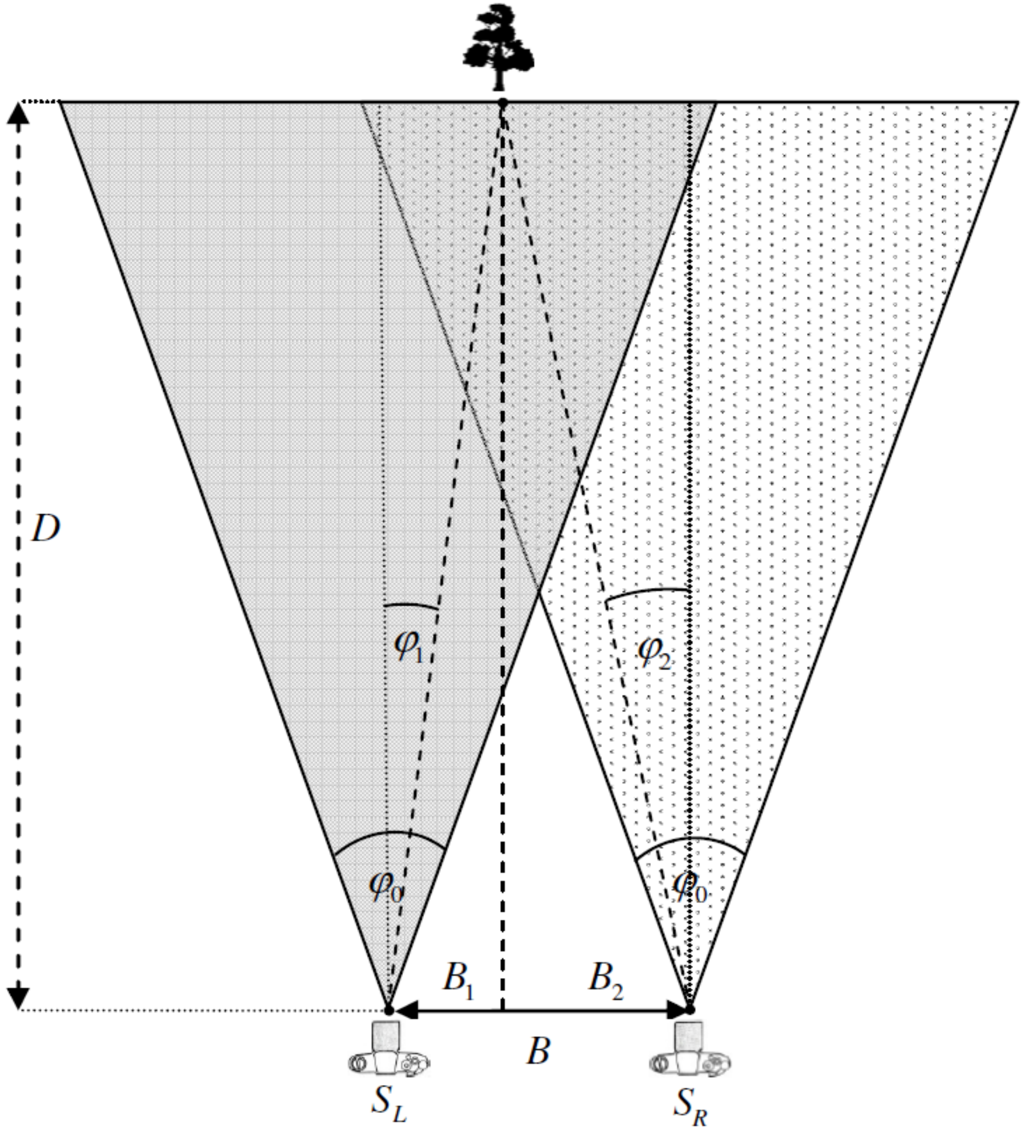
- Stereoscopy



Source: [5]

Distance Sensors - Vision

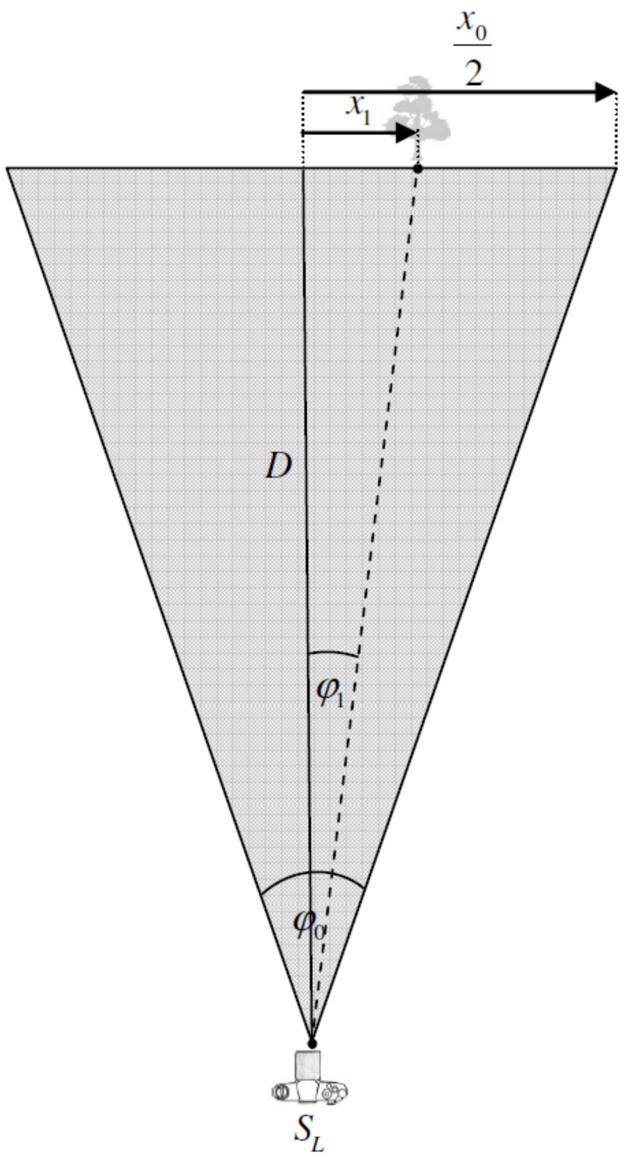
- φ_0 horizontal angle of view
- $\varphi_{1,}\varphi_2$angle between optical achsis and object
- Distance between cameras
  - $B = B_1 + B_2$
  - $B = D\tan(\varphi_1) + D\tan(\varphi_2)$
- Distance between cameras and object
  - $D = \frac{B}{\tan(\varphi_1)+\tan(\varphi_2)}$



Source: [5]

Distance Sensors - Vision

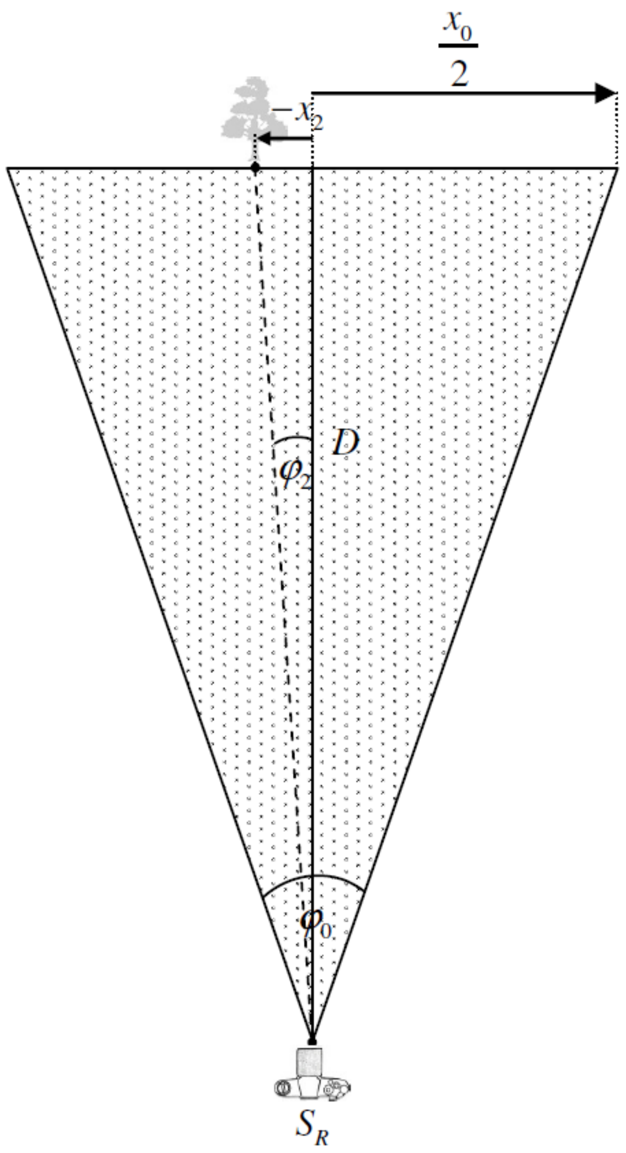
- Number of horizontal pixels x_0
- $\frac{x_1}{\frac{x_0}{2}} = \frac{\tan(\varphi_1)}{\tan(\frac{\varphi_0}{2})} \Leftrightarrow \tan(\varphi_1) = \frac{2x_1 \tan\left(\frac{\phi_0}{2}\right)}{x_0}$



Source: [5]

Distance Sensors - Vision

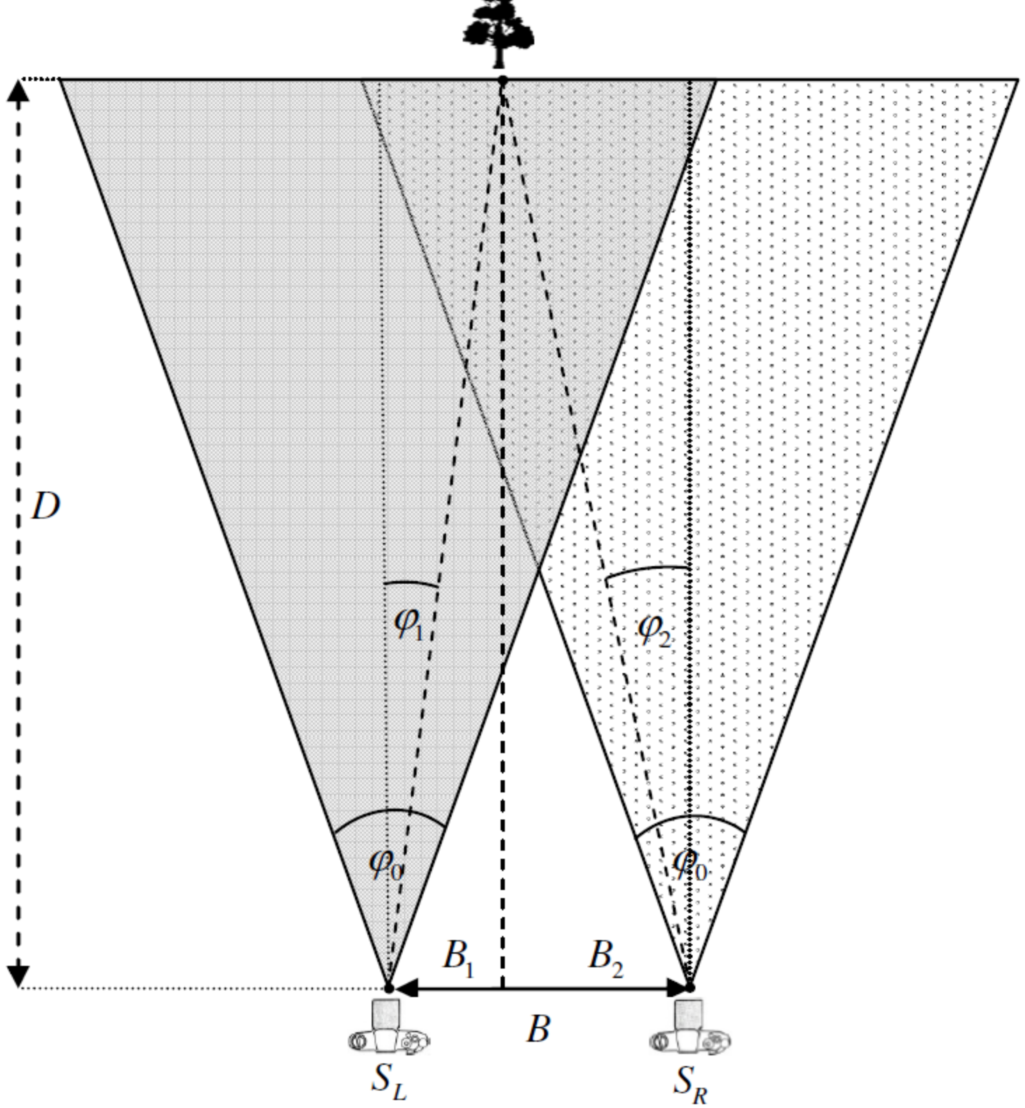
- Number of horizontal pixels x_0
- $\frac{x_1}{\frac{x_0}{2}} = \frac{\tan(\varphi_1)}{\tan(\frac{\varphi_0}{2})} \Leftrightarrow \tan(\varphi_1) = \frac{2x_1 \tan\left(\frac{\phi_0}{2}\right)}{x_0}$
- $\frac{-x_2}{\frac{x_0}{2}} = \frac{\tan(\varphi_2)}{\tan(\frac{\varphi_0}{2})} \Leftrightarrow \tan(\varphi_2) = \frac{-2x_2 \tan\left(\frac{\phi_0}{2}\right)}{x_0}$
- $D = \frac{B}{\tan(\varphi_1)+\tan(\varphi_2)} = \frac{Bx_0}{2\tan\left(\frac{\varphi_0}{2}\right)\cdot(x_1-x_2)}$



Source: [5]

Distance Sensors - Vision

- $D = \frac{Bx_0}{2\tan\left(\frac{\varphi_0}{2}\right)\cdot(x_1 - x_2)}$
- To compute D we need
  - Distance B
  - Number of horizontal pixels x_0
  - Diff. between object in both pictures $(x_1 - x_2)$



Source: [5]

Distance Sensors - Vision

- Accuracy
- Marker at 10m, 20m, …, 60m
- Distance $B = 0.7m$
- Measured at 4 different locations

Source: [5]

Distance Sensors - Vision

- Accuracy

Location 1	Location 2	Location 3	Location 4	Avg. Distance	Market at
10,18m	9,84m	9,96m	10,13m	**10,03m**	10m
20,44m	20,41m	20,41m	19,86m	**20,28m**	20m
30,74m	30,33m	31,25m	30,71m	**30,76m**	30m
41,12m	40,84m	39,73m	40,05m	**40,44m**	40m
52,30m	52,05m	53,85m	50,07m	**52,07m**	50m
61,57m	61,40m	61,75m	60,55m	**61,32m**	60m

Source: [5]