Visual Perception Sensors

Depth Determination

Gerrit Glaser

University of Hamburg
Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics

Technical Aspects of Multimodal Systems

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Motivation for Visual Perception in Robotics

- basic question for mobile robotics: Where am I?
- autonomous movement through unknown terrain
  - scan environment for obstacles
  - distances to surroundings

Possible solution

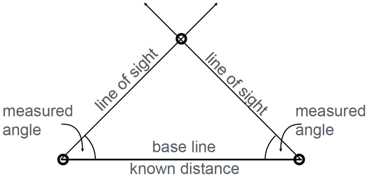
Add visual perception sensors, to allow robots to “see” their environment.

Camera

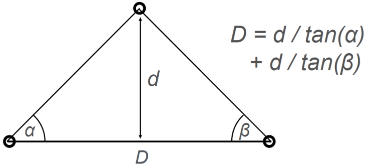
- image as projection of 3D world: leads to loss of depth data
- estimate depths through known size of an object and size of the object in the image.
- error-prone, even in human visual perception
- not applicable outside of known surroundings
- passive approach

Stump in Sequoia National Park. [1, p. 529, fig. 2]

- compute point through known distance and measured angles



Triangulation. [7, p. 19, fig. 1]



Triangulation Calculation. [7, p. 20, fig. 1]

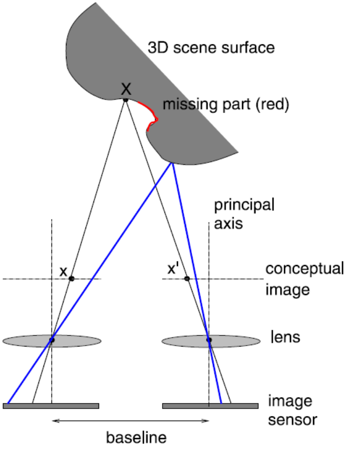
Stereoscopic Cameras

- one camera not sufficient for meaningful depth measurements
- use second camera to recover lost dimension
- triangulate distance
  - known baseline between cameras
  - corresponding points
  - measured angles
- passive approach

Rotated stereo-camera rig and a Kinect. [6, p. 5, fig. 1.2]

Stereoscopic Cameras
Problems

- identification of corresponding points in both images
- occlusion
- computationally expensive
- depends on illumination
- cameras need to be synchronized



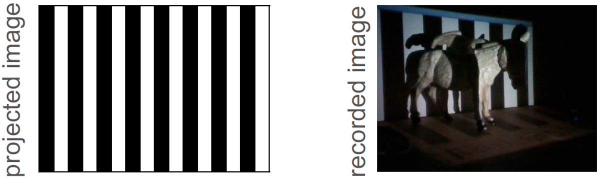
Stereo-Camera example. [5, p. 38, fig. 2.1]

Structured-Light

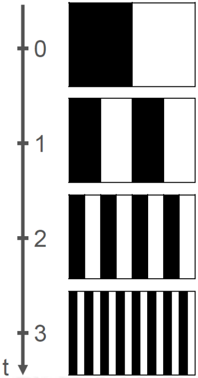
- project additional information on the object to allow recovery of lost depth dimension
- several different approaches
  - time multiplexing
  - spatial multiplexing
  - wavelength multiplexing

Binary Projection

- one camera, one projector
- several passes required
- deformity of lines as measure for depth
- time multiplexing
- active approach



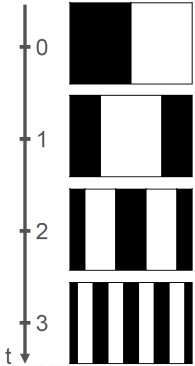
Binary projection. [7, p. 30, fig. 1]



Binary projection at different times t. [7, p. 33, fig. 1]

Binary Projection
Problems

- frames taken at different points in time
  - time multiplexing
  - not applicable for moving objects
- points directly on edges are uncertain
  - soultion: gray code pattern



Gray code projection at different times t. [7, p. 33, fig. 1]

Microsoft Kinect

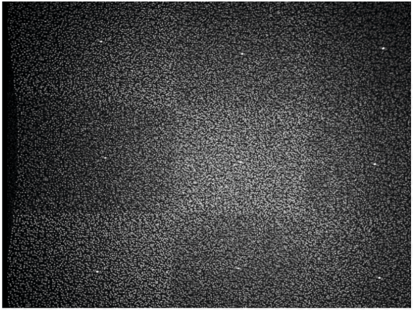
- RGB camera: 30fps @ 640x480px
- spatial multiplexing
- USB 2.0

- depth image: 30fps @ 320x240px
- practical range [4]
  - 0.8-4.5m in default mode
  - 0.4-3m in near mode

Microsoft Kinect. [3, p. 2, fig. 1-1]

Microsoft Kinect
IR Laser Emitter

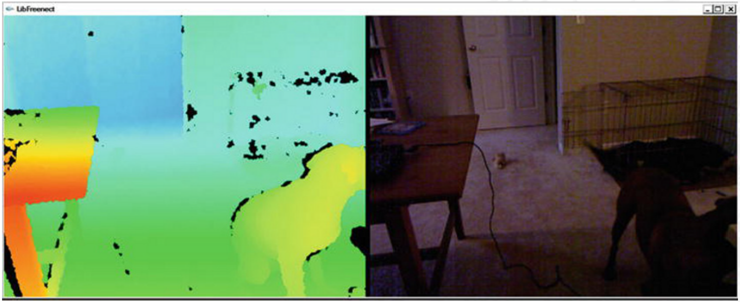
- projection
  - pseudo random noise-like pattern
  - 830nm wavelength
- laser
  - heated/cooled to maintain wavelength
  - 70mW output power
  - eye safety through scattering



Projected IR pattern. [3, p. 12, fig. 2-2]

Microsoft Kinect
Depth Image

- IR camera image compared to known pattern
  - disturbances can be used to calculate distances
- distances visualized as depth images
  - red areas: close
  - blue areas: further away
  - black areas: no depth information available



Depth image and corresponding RGB image. [3, p. 9, fig. 1-3]

- overexposure of IR camera
  - by sunlight (only usable indoors)
  - by reflecting surfaces
- only close range distances
  - limited by laser output
- translucent objects not measurable
- latency of ~100ms [4]
- active approach, not easy to scale-out
  - interferences with projected patterns

Triangulation Approaches Conclusion

Stereo Cameras

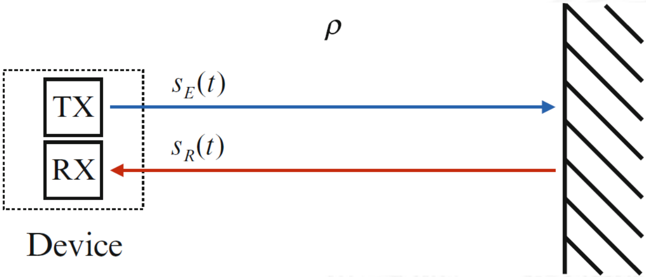
- good to calculate depths for distinct markers
  - otherwise computationally expensive
- works indoors and outdoors
- completely passive, scaling out is possible without problems

Triangulation Approaches Conclusion
Structured-Light Cameras

- all approaches
  - trouble measuring reflecting or transparent objects
- time multiplexing
  - depth calculation for whole field of vision
  - only for stationary objects
- spatial multiplexing (Kinect)
  - computation done by hardware
  - pretty complete depth map
    - occluded areas
    - too close or too far points
- wavelength multiplexing
  - depth calculation with one photo
  - low spatial resolution achievable

Time of Flight Approaches

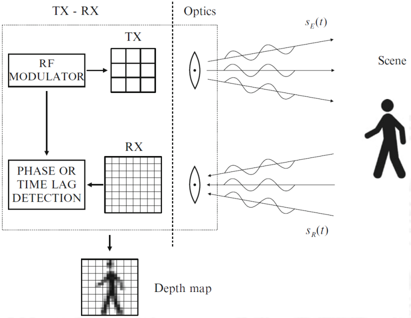
- actively send out a signal
- measure time until reflection returns
- Light: $P = \frac{299.792.458 \frac{m}{s} * t}{2}$



Simple ToF measurement. [8, p. 28, fig. 1.14]

Depth Camera

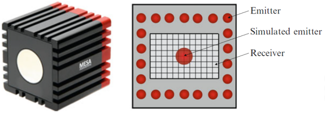
- active approach
- TX: illuminates whole scene with array of IR emitters
- RX: ToF-receiver grid
- commonly used: sinus modulation for emitted light
- measure point in time when emitted signal returns
- calculate distance through ToF



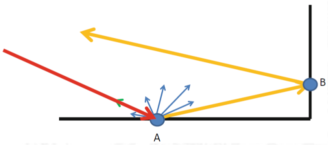
MESA Imaging SR4000, IR emitters. [8, p. 32, fig. 1.16]

Depth Camera
Problems

- hardware restrictions
  - IR-emitter and ToF-receievers in different position
  - simulate central emitter to avoid occlusion effects
- falsification of measurements through multi path hopping
  - point B will measure a combination of two distances
- accurate time measurement required



Pattern of IR emitters to avoid occlusion. [8, p. 34, fig. 1.17]



Multipath phenomenon. [8, p. 104, fig. 3.16]

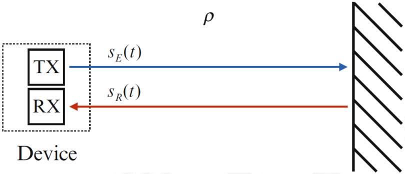
Kinect V2

- depth image: 50fps @ 512x424px
- range 0.5-8m [4]
- latency of ~50ms [4]
- square wave modulation
- differential pixel array
  - switches with square wave
  - save returned light
  - difference used to compute distances
- high volume of data, requires USB 3.0

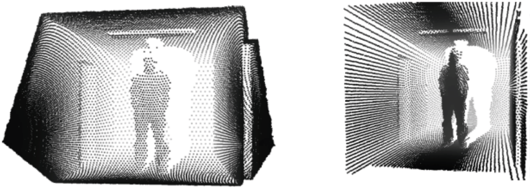
Kinect V2. [4, p. 6, fig. 1-5]

LIDAR

- **L**i**ght** **D**etection **A**nd **R**anging
- sends out single laser beam
- ToF to calculate distance
- single point sampling
  - mirrors rotate laser beam to scan line of points
  - additional rotation possible to scan area instead of line



Simple ToF measurement. [8, p. 28, fig. 1.14]



Point clouds created by rotated line scanners. [2, p. 46, fig. 2.21]

LIDAR
Problems

- loss of spatial resolution with increased measurement distance
- transparent objects can not be measured
- mechanical moving parts

- high laser outputs possible
  - high measurement range
  - sunlight can be compensated
- high sampling rates possible
- dynamic measurement range
  - short and long distances can be measured together

Conclusion
Required Ambient Lighting

- structured light approaches require dark surroundings
  - often used for optical measurements and inspection in industrial robotics
  - very precise measurements
- LIDAR can be built for outdoor usage
- other active approaches falsified/annulled by direct sunlight

Conclusion

Computational Costs

- active approaches
  - distance calculation mostly handled by hardware
- stereoscopic cameras
  - expensive: calculate matching points in both images

Conclusion
Moving Objects

- depth cameras, spatial multiplexing structured light
  - well suited
  - record whole scene at single point in time
- binary projection
  - not usable, time encoding through different frames
- LIDAR
  - suitability depends on sampling rate and object movement

	Triangulation			Time-of-Flight	
	Stereo Camera	Binary Projection	Kinect	Kinect V2	LIDAR
outdoor usability	✓	✗	✗	✗	(✓)
complete depth map	(✗)	✓	✓	✓	(✓)
passive	✓	✗	✗	✗	✗
scale out	✓	(✗)	(✗)	(✓)	(✓)
moving parts	✗	✗	✗	✗	✓
“cheap”	(✓)	✗	✓	✓	✗

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