3D Computer Vision

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Reconstruction by Special Devices

Outline

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- Motivation: Objects can be scanned by the help of artificial illumination
- More accurate reconstruction can be obtained.
  - Bottleneck of standard camera-based vision: correspondences between images.
  - Illumination can help correspondence detection.
- Weak-point: usually, good illumination requires indoor environment (laboratory)
- Existing solutions:
  - Laser-scanning
  - Structured-light scanning
  - Depth cameras
    - Outdoor depth cameras exist.
  - etc.

Outline

Laser scanning

- Equipment: camera + laser stripe illuminator.
  - Camera and laser must be fixed to each other.
- Calibration is required.
  - Chessboard-based calibration by switching the laser on/off.
  - Location of laser stripe can be determined in the plane of the chessboard.
  - Plane of illumination can be determined from at least two chessboards.
    - More than two chessboards: plane estimation in 3D is overdetermined.
- Reconstruction:
  - A laser point determines a ray by back-projection.
  - Spatial point: intersection of the laser plane and the back-projected ray.

Laser scanning: calibration

- Calibration by chessboard
  - Camera intrinsic parameters are known.
  - Chessboard illuminated by the laser stripe.
  - Image and spatial chessboard positions can be transformed into each other by a homography.
  - Line of the laser stripe in 3D: points transformed by the inverse of the homography.
  - More lines: they are in the same 3D plane.
- Plane fitting to spatial lines
  - Lines sampled as points $\rightarrow$ plane fitting possible from at least two lines
  - Plane point $\mathbf{p_0}$: center of gravity $\rightarrow$ Let origin be $\mathbf{p_0}$.
  - Normal and tangent directions $\mathbf{v_1}$ and $\mathbf{v_2}$ can be determined by Principal Component Analysis (PCA)
    - PCA is obtained by Singular Value Decomposition.

Laser scanning: 3D Reconstruction

- Pixels corresponding to laser stripes can be detected in images.
- A projective ray can be determined by back-projecting the pixel using camera parameters.
  - Ray can be written e.g. parametric form: $\mathbf{q_0} + t\mathbf{w}$, where t is the parameter of the line.
    - $\mathbf{q_0}$: focal point
    - $\mathbf{w}$: direction of the ray
- Spatial point: intersection of projecting ray and plane of the laser.

$$\mathbf{q_0} + t\mathbf{w} = \mathbf{p_0} + a\mathbf{v_1} + b\mathbf{v_2}$$

  - Three linear equations as each coordinate serves one equation
- Unknown parameters are t, a, and b.
- Solution: obtained parameters substituted into left or right side of the linear equation.

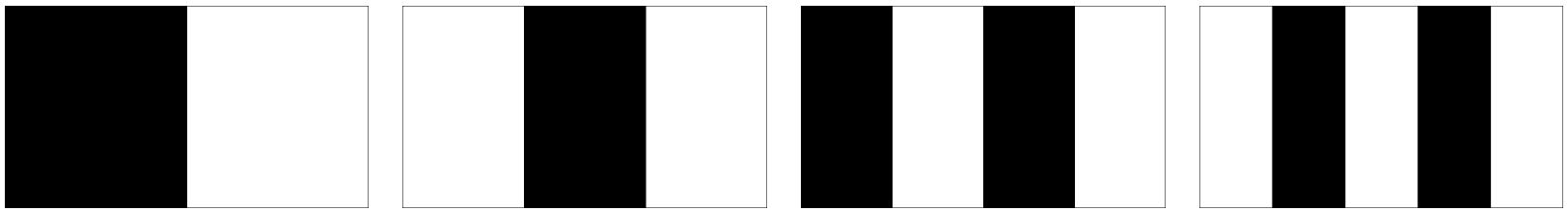
Outline

Structured-light scanning

- Special patterns are projected onto object surface.
  - Standard projector can be applied.
  - Non-visible, e.g. infra, light can be used.
  - Camera and projector have to be fixed to each other.
- Calibration is required.
  - Chessboard can be illuminated by the projector.
  - Projector equals to an inverse camera: it illuminates and not projects.
  - If chessboard pose known in 3D, pattern positions can be computed by a homography.
  - Key-question: what kind of pattern is illuminated?

Structured-light scanning

- Goal of pattern: to help the detection of corresponding points
- Vertical and horizontal striped are illuminated, different stripe thickness applied
- Striped encodes row/column numbers of projector pixels
  - Trivial, binary coding: n-th bits of column/row number yields color in n-th illumination
  - Correction codes can also be applied to improve reliability.



Structured-light scanning

- It is assumed that
  1. Cameras are calibrated (using e.g. chessboard)
  2. Projector is calibrated (chessboard + illumination)
  3. Camera-projector correspondence can be detected by coding
     - Only bright/dark pixels have to be separated
- Spatial reconstruction: by stereo triangulation

Modified structured-light scanning

- Other patterns can be illuminated.
  - Finer resolution, more images
  - Phase shifting of the laser light can be applied.
- Reconstruction from a single image is also possible
  - Dots can also be used as patterns
  - Microsoft Kinect
    - Infra projector + camera
    - Depth image is computed by the device
    - Depth image + color : RGB-D camera

Outline

Depth camera

- A flash emits light, usually infra-red light applied.
- Camera detects light.
- Time of flight (TOF) between emittance and detection is measured.
  - These cameras are also called ToF cameras.
- Speed of light known, distance can be calculated.
- Output: depth image, small resolution.
  - Rapid circuits required.
  - Depth granulation is quire small (approx. centimeter)

LIDAR: Light Detection and Ranging

- Spacial depth camera.
- Camera is rotating, 360 degree scanning is possible.
- Frequently used in autonomous vehicles.
  - Car (e.g. Google Street View)
  - Trucks (Knorr Bremse)
  - Airplanes
- Output: sparse point cloud.