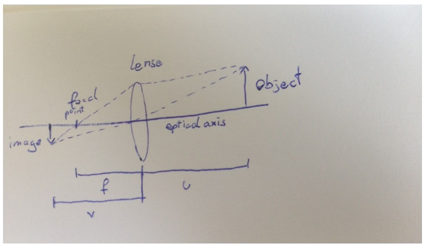
Theory

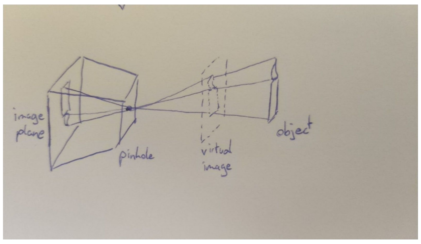
1. Thin Lense Equation (Sketch, Formula)

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$



2. Pinhole-Camera

Abstract camera-model, box with small hole in it, distant objects look smaller, image flipped and upside down on the back of the box



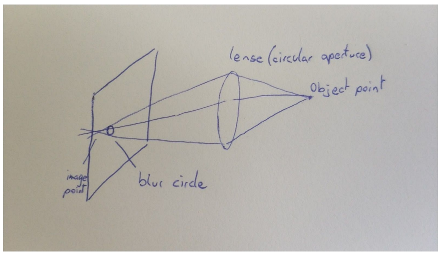
3. Vanishing Point / Vanishing Line?

Vanishing point is the point of a line in central projection, where the line cannot be continued. Vanishing point of a line depends only on the orientation of the line.
Each set of parallel lines escapes in a different point.
Sets of parallel lines on the same plane lead to collinear vanishing points = Vanishing Line

4. Depth of Field Problem

Only objects in a certain distance are imaged sharply. All other distances are blurred because of blur circles. Bigger aperture = bigger blur circles, smaller aperture =

sharper image.

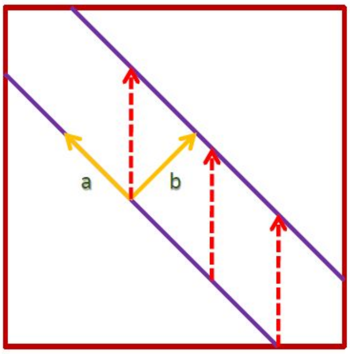


5. Aperture Problem?

Aperture too small → less light gets through, diffraction effect

OR

we can determine only the component of motion parallel to the gradient, but not normal to the gradient direction;



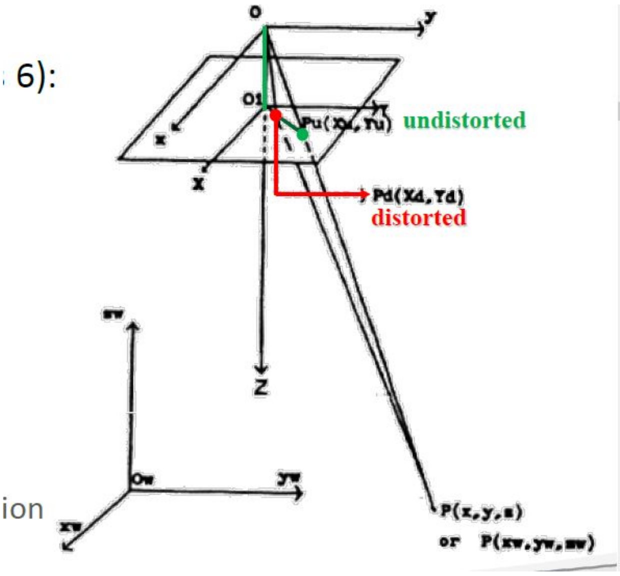
6. Intrinsic camera parameters (+ Sketch)

Principal point - C_x , C_y (intersection of optical axis with image plane)

Scaling - s (sampling factor in x direction)

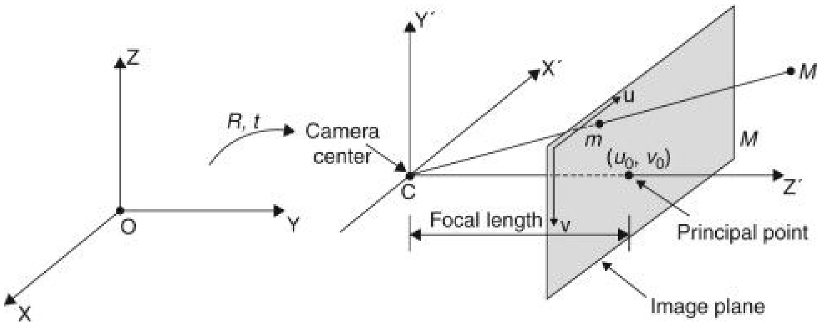
Focal length - f (distance image plane - projection center)

Distortion coefficient - k_1 , k_2 (lens distortion)



7. Extrinsic camera parameters (+ Sketch)

3 euler angles - yaw, pitch, tilt (rotation of the two coordinate systems)
3 translational vector components - tx, ty, tz (displacement world coordinate system to center of projection)



8. Camera problems

Optical distortions (Blur, Lens Glare, Vignetting)
Geometrical aberrations (spherical, astigmatism, distortion, chromatic) → reducible by combining lenses
Radial distortion (pincushion/barrel effect - straight lines not imaged straight)
Lens distortion (radial and tangential)
Motion Blur, Blooming / Smearing
Gamma distortion

9. How to calibrate a camera?

Linear Calibration
Classical approach (Photogrammetry) - use precisely known 3D points (not flexible)
(linear)**Simple Calibration** - Creation of a calibration plate, positioning in field of view of camera, acquisition of image, affine transformation of image points, undistortion matrix
Non-linear Calibration (Tsai Calibration)
Move origin of world coordinate system by translating the center of projection, then rotate it to coincide with the camera coordinate system. (R and t)
Camera coordinate system → undistorted image coordinate system (f)
Consideration of lens distortion (k_1 and k_2)
Metric- image coordinate system → pixel- image coordinate system (scale factor s_x)
Calibration from 2D motion
Move camera in a static environment - match feature points across images (not always reliable)
Radiometric Calibration because different sensitivity of photosensitive elements → taking image with the same brightness on all image points → scaling coefficients for each pixel, images with different brightness (gamma correction)

10. Explain photometric stereo.

2 images with same geometry but different illumination directions; RM limits possible surface orientation only by one iso brightness contours → many possible directions
2 RM restrict possible directions of a surface normal to 2 candidates
Solve by using a third lightsource

11. What is the reflectance map.

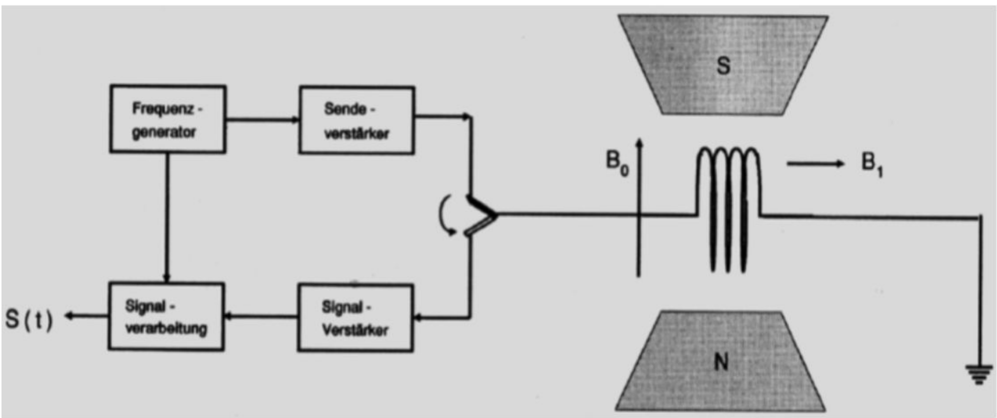
2dim plot of gradient space (p,q) of normalised image brightness of a surface as function of surface orientation
Relates image irradiance I(x,y) to surface orientation (p,q)
Standard form: Ellipse = specular reflection, Parable = transition diffuse - specular, Hyperbola = diffuse, Line = boundary light - shadow (Terminator)

12. Computed tomography

CT scan produces axial slices, CT image is recorded through a scan, a scan is made of made up of multiple x-ray attenuation measurements around and objects periphery (x-rays pulsating scan layers of body → propagation delays produce image)

13. Magnetic Resonance Imaging

The object is located in a homogenous static magnetic field (B_0)
Using a RF coil a magnetic RF field B_1 is radiated perpendicular to B_1
After excitation, the magnetic resonance signal of the object received in the coil through receiver electronics is sent to the computer



14. Explain how ultrasound range finder work. (+ Pros and Cons)

Same as laser range finder (phase between transmitted and returned signal is used to determine the distance).
Pros: Illumination independent, low speed beam Cons: Poor resolution, low accuracy, deflector necessary
Applications: Obstacle detection, underwater measurements, …

15. Stereo Vision (epipolar line, epipole, baseline, disparity, ...)

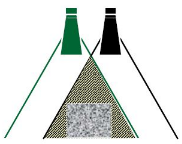
Baseline: line joining the camera centers
Epipole: point of intersection of baseline with the image plane
Epipolar plane: plane containing baseline and world point
Epipolar line: intersection of epipolar plane with the image plane
Disparity: Difference in location of an object in the right and left image

16. 2 Solutions for the correspondence problem

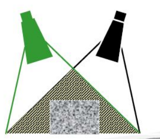
Area based: comparison of intensity values, correspondence due to similarity between intensity values, correspondence for each pixel (window size important, may be varying)
Feature based: comparison of features in left and right image; correspondence based on selected characteristics/features (edge orientation, gradient, …), correspondence for selected pixels, more accurate because of sub-pixel positioning of features

17. Rectification of Images (Stereo normal case, ...)

Process to align epipolar lines horizontal
Rectify = horizontally align epipolar lines of the images
For calculation purposes, two stereo images are registered to each other (transformed into one image plane, epipolar lines = lines of the images)
Simplest case (normal case): During imaging this geometry is generated



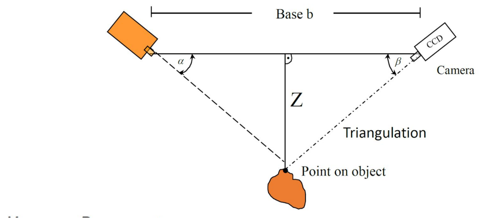
Disadvantage: small distance between the centers of projection
Advantage: low computational complexity
General case: larger distance between projection centers = more accurate measured value



BUT large distance = large inclination angle = large occlusion ares

18. Erklärung des Triangulationsprinzips bei Rangefinder

Sine-law: 1 distance +2 angles
basic optical triangulation: pinhole model - light beam is generated by a laser is deflected at an angle alpha, position of the diffuse image of the laser beam is



measured by the imaging device. (alpha, beta, base are known).

19. Erklärung des Triangulationsprinzips bei Stereoaufnahmen

2 or more images taken from different positions + geometric calibration of the camera → perspective projections of object points → depth calculation is performed by means of triangulation: object point must be on line between the center of projection and pixel (both pictures) "Stereo Correspondence"

20. Welche Parameter beeinflussen die Genauigkeit der Rangefinder/Stereoaufnahmen?

21. What types of ToF-Rangefinder are there?

Pulsed (Lidar), Continuous modulation (AM, FM, …)

22. Describe one ToF-Rangefinder type.

AM Modulation:
Amplitude modulation of the laser; Phase between transmitted and return signals; Ambiguity for 360 deg phase: multiple frequency

23. DOV?

Depth of View = distance between the nearest and farthest object points that can be scanned

24. Shape from Motion

Motion of an observer relative to the environment; Problem: moving direction and amount of camera movement
Prerequisites: known moving direction of camera, known speed of camera 3rd dimension = time
Correct assumptions → depth calculation possible

25. 3D from Motion

26. Shape from Polarised Light

Similar approach to anaglyph (projector left right with polarizing filters with crossed axis), polarization differentiates L-R channel, screen must be polarization-preserving (silver screen);
polarizing glasses with filter positioning as on the projectors;

27. FOE & FOC?

FOE = Divergence of the vectors = forward movement
FOC = field of convergence of the vectors = backward movement
Intersection between movement direction and image plane. (Movement = 0 → convergence/divergence of all motion vectors)

28. Motion Field

Projection of movement onto the image plane. Field of Motion vector, each vector represents movement of the scene point between two frames

29. Motion Vector

Amount of motion vector is proportional to the sine of the line of sight between a point and the moving direction. Determined by image-plane velocities.

30. Optical Flow

is the relation of the motion field to 2D displacement of pixel patches on the image plane. 2D projection of physical movement of points is relative to the observer.

31. Intensity Flow

Lighting direction does not change, image brightness is continuously differentiable on image plane and time

32. Shape from Video

Recover 3D shape from sequence of images. Motion and calibration of the camera are recovered. Fully automatic.

33. Why do light edges appear in shape from shading?

34. How does shape from shading work?

Strip method:
For each brightness value of a pixel → Reflectance Map restricts surface orientation;
Strips of equal brightness in picture = height lines
Starting point with known surface normal
Small movement in the direction of greatest change in brightness → small movement in the direction of greatest slope

35. How do light strip techniques work?

Projection of a light plane onto the object, section of the plane of light visible to the object surface is a light strip, localisation of the light strip by means of edge detection and segmentation

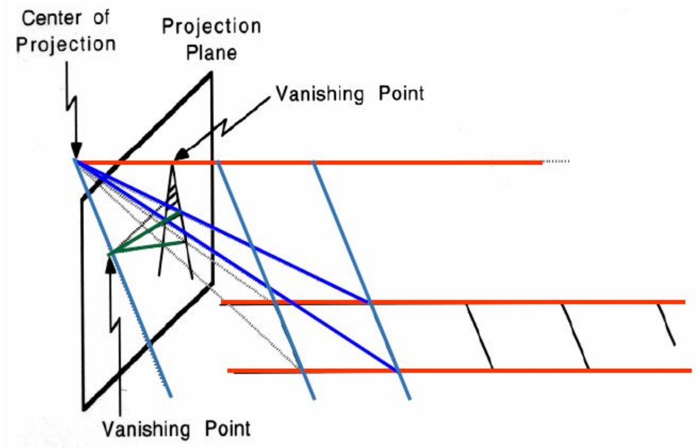
36. Most common error in stereo vision?

37. Prerequisites for shape from texture?

Texture is scale-dependent, must not exceed a maximum number so that the size of the elements is smaller than the sensor resolution.
Shape from texel: texel must be clearly identifiable, texels must not overlap, texels have same spatial extent, texel are small => planar and unique surface normal

38. Wie kann man mittels Fluchtpunkt/Fluchtlinie Aussagen über die Szene treffen?

Mit hilfe des Fluchtpunkts und Fluchtlinie lassen sich parallele Geraden rekonstruieren.



39. Explain the normal projection (+ Equation)

Each 3D point is projected by rays normal to the image plane. z = infinite. x = X, y = Y.

$x = \frac{f}{Z} X$, $y = \frac{f}{Z} Y$

40. Möglichkeiten der Registrierung von Punktwolken

Point cloud registration, target based registration (targets coordinates measured by geodesic surveying instruments, identify/measure the targets in the point clouds, apply a chained 3D similarity transform), surface based registration (solely point cloud data used for registration, simply bring strenuous additional scanning to the computer in the office)

41. Wofür verwendet man Tracker/Marker?

Markers are physical objects placed near surface to be acquired
recognised by scanner → position used as reference for rough and fine registration;

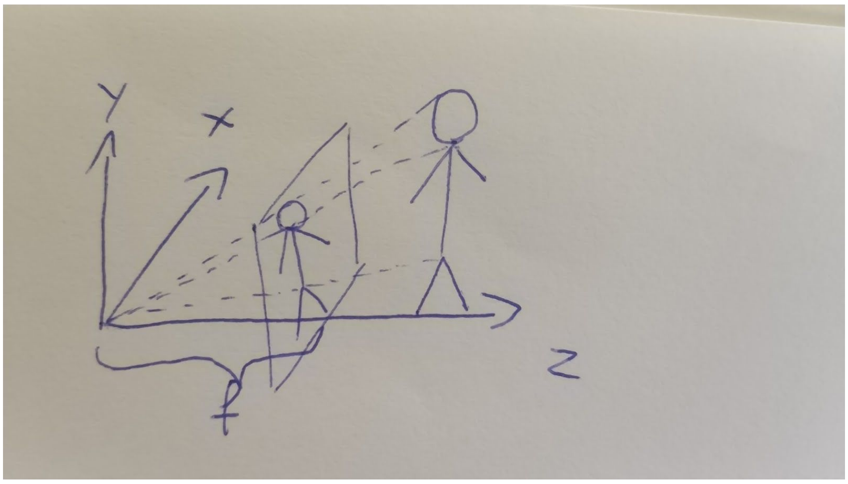
42. Was ist der Iterative Closest Point Algorithmus, wie funktioniert er?

the scene shape S should be aligned to be in the best alignment with the model Shape M → distance minimised;

init the error to infinity
calculate correspondence;
calculate alignment;
apply alignment;
update error;
if error > threshold go to step 2;

43. Erkläre Central Projection + Skizze

= Perspective projections;
Angle don't stay the same; Points → Points, Lines → Lines; Planes → half or full image;



44. Was ist der 3D Printer SLS, FDM, SLA, DLP und EBM

SLS = Selective Laser Sintering
Platform with layer of powder; Fuse powder with laser; Lower platform and add powder → repeat;

FDM = Fused Deposition Modeling
Squirt semi-liquid material (plastics, wax, chocolate..); Add layer by layer; Nozzle is heated to melt material and is moved horizontally and vertically

SLA = Stereo Lithography
Tank of liquid polymer; harden (polymerize) with laser beam; accurate/fast

DLP = Digital Light Processing
Same as Stereo Lithography, but instead of a lasser a DLP projector is used

EBM = Electron Beam Melting
Power source = beam, melting metal powder layer by layer in vacuum,parts are fully dense, void-free and extremely strong;

45. Was ist active stereo?

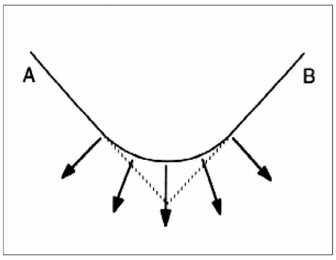
Feature based methods not useable with objects that have smooth surface;
Patterns of light can be projected onto surface of objects, creating “interesting” points;
Problem: Ambiguity → use multiple cameras reduces likelihood of false matches

46. Reflectance Map, was genau bedeuten die beiden Parameter (p, q)?

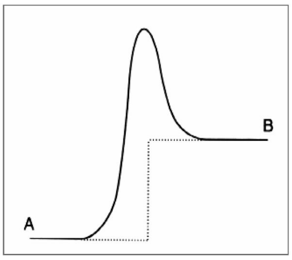
Those parameters are the surface orientation

47. Was sind Image Intensity Corners

Relationship between image brightness and surface shape is not always clear, rounding of a surface edge does not lead to rounding of the edges calculated but to overshooting;



Rounded corner of the object



Brightness profile along the corner

48. Erkläre Space Carving

Algorithm: Initialise volume containing the true scene; choose a voxel on the surface; project to visible input images; carve if not photo-consistent; repeat until convergence;

49. Was ist Shape from Silhouette

Silhouette of object contains 3D information; only binary images are used; voxel is photo-consistent if it lies inside silhouettes of all views; final model = intersection of all conic volumes;

50. Erkläre Zippering

The surface is built using parts of each single scan, simply joined together;
Can be recognized from triangulation: some areas are covered with regular triangle grid, joined by strips of triangles (zipper).

51. Post-Processing Schritte von Point Cloud Matching

Registration (pairwise registration, global registration), Point Cloud editing (cropping the area of interest, noise reduction, down-sampling), Surface Triangulation and editing, Texture Mapping, Visualisation
(Cleaning, Simplification)

52. Was ist ein Texel (Eigenschaften und wie werden sie verwendet)

One very restrictive definition: “Repeating patterns of local variations in image intensity which are too fine to be distinguished as separate objects
The patterns that repeat are referred to as **texels”**
Texels = repeating patterns
Properties: clearly identifiable; not overlapping; same spatial extent; small, planar and unique surface normal
Used for Shape from Texels.

53. Was ist die durchschnittliche Genauigkeit und maximaler Abstand der Kamera bei Triangulation, ToF und Laser Radar?

Measurement uncertainty:
Triangulation Range Camera = 0.1 mm,
TOF = 2 - 20 mm
Laser Radar = 0.1 mm

Rechenbeispiele

1. Abtasttheorem: Eine Kamera soll ein Objekt mit der Größe 1m x 1m aufnehmen und Details von 2mm darstellen. Welche Auflösung muss die Kamera in x- und y-Richtung haben?

1m x 1m, 3mm erkennen → (1000 / 3 * 2) A: 667x667
1m x 1m, 2mm erkennen → A: (1000 / 2 * 2) = 1000x1000

1000 → Millimeter des Objekts
3mm → Details des Objekts

2 → Abtasttheorem

2. Stereoauswertung: ein gegebener 3x3-Filterkern auf eine gegebene Zeile eines Bildes anwenden und den Punkt mit dem besten Ähnlichkeitsmaß ermitteln (Formel zur Berechnung des Ähnlichkeitsmaß war ebenfalls gegeben). Für diesen Punkt dann die Disparität berechnen.

   Jeden Wert mit dem Filterwert multiplizieren dann die Werte aufsummieren.
   In Ähnlichkeitsmaß einsetzen (mit anderen Punkt).

3. Shape from Stereo: Z (Abstand zum Objekt) berechnen für Stereo (f - fokale länge, b - basisbreite, D - disparity gegeben). Triangulation Z berechnen (alpha, beta und b gegeben).
   $- Z = \frac{b*f}{D}$, $Z = \frac{b * sin(\alpha) * sin(\beta)}{sin(180 - \alpha - \beta)}$

   Objektpunkt = 40 cm
   Basislinie = 5 cm
   Disparität = 4 mm
   Gesucht: Fokale länge

   Z*D/b = 400*4/50 → 32 mm

4. Bildhöhe berechnen (Z, f, Objekt-höhe, DPI von Sensor gegeben). Projizieren sie eine Stange auf die Bildebene und berechnen Sie die Höhe der Stange auf der Bildebene sowie die Vertikale Auflösung in Pixel (mithilfe der DPI des Sensors 1 mm = durch 25,4).

   Bildhöhe = y gesucht!
   Objekthöhe = Y
   fokale länge = f
   Distanz vom Objekt = Z
   DPI = dots per inch

   Formel $y = \frac{f}{Z} Y$, y in inch umrechnen: $y * 0.039$ dann mit DPI multiplizieren!