Computer Vision and Machine Learning

(Shape from structured light)

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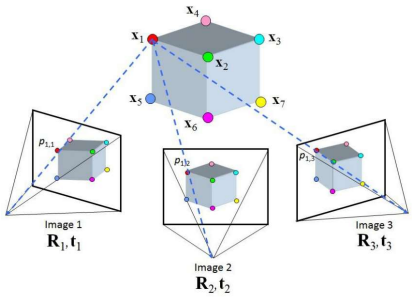
Acknowledgement

- http://www.cs.cmu.edu/afs/cs/academic/class/15385-s06/lectures/ppts/lec-17.ppt
- http://mesh.brown.edu/byo3d

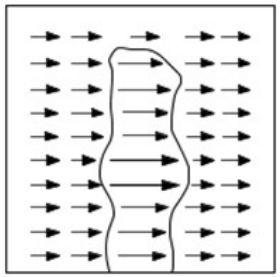
Shape from X

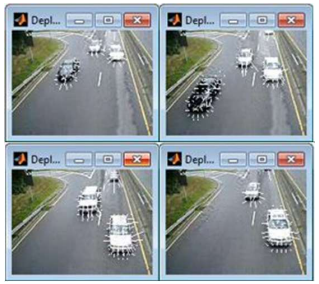
- Reconstructing 3D object from 2D images
  - Stereo
  - Motion
  - Shading
  - Texture
  - Focus
  - … etc.

Shape from motion



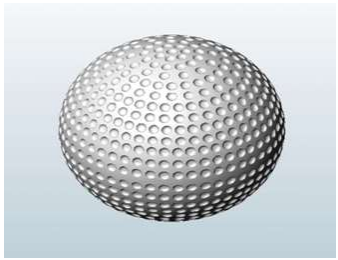
Depth from motion



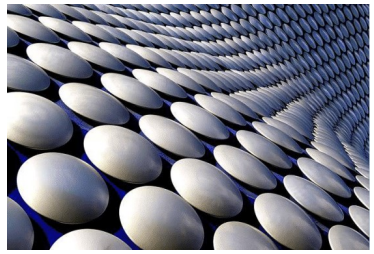


Nearer objects show larger translation parallel to surface.

Shape from texture



Example-1



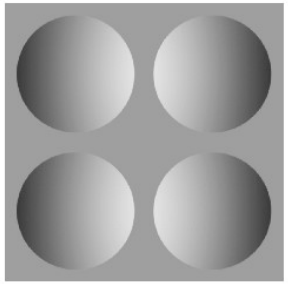
Example-2

Shape from focus

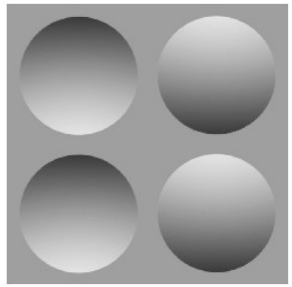
Focus on foreground

Focus on background

Shape from shading



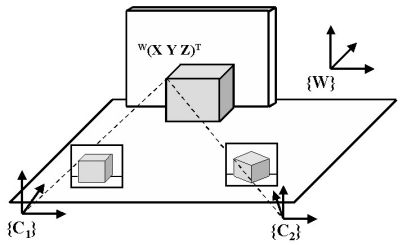
Horizontal lighting



Vertical lighting

Passive triangulation: Stereo vision

- Keypoints detection in the images
- Correspondence problem
- Geometric constraints → search along epipolar lines
- 3D reconstruction of matched pairs by triangulation



Passive Stereo vision: Problems

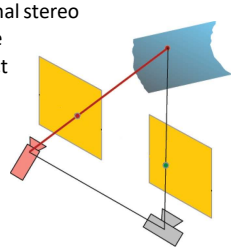
- The main problems of photogrammetry
  - to recover shape from multiple views of a scene, we need to find correspondences between the images
  - the matching/correspondence problem is hard
  - the 3D object geometry cannot be reconstructed in image regions without well-defined image points
- Plausible solution: Structured light

Structured Light

- Structured light (active stereo)
  - idea: find ways to simplify matching and guarantee dense coverage with homologous points
  - general strategy: use illumination to create our own correspondences
  - most robust and widely used method

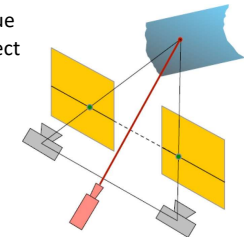
Basic Principle

- Light projection
  - use a projector to create unambiguous correspondences
  - with these correspondences, apply conventional stereo
  - if we project a single point, matching is unique
  - ... but many images needed to cover the object
  - NOTE: ray on the left is in opposite direction

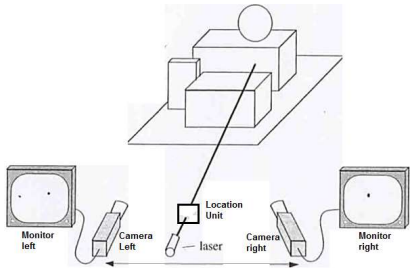


Basic Principle

- Light projection
  - use a projector to create unambiguous correspondences
  - with these correspondences, apply conventional stereo
  - if we project a single point, matching is unique
  - ... but many images needed to cover the object
- In general, various types of light patterns may be projected.
  - Vertical stripe, horizontal stripe
  - Cross-check stripe
  - Collection of dots pattern



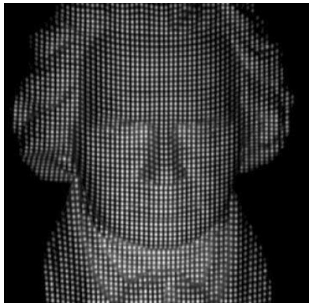
Light Spot Stereo: Set up



Calibrated Cameras: Detection of spot in left and right cameras fully determines its 3D location. Spot to be scanned across scene. Many images required for whole scene.

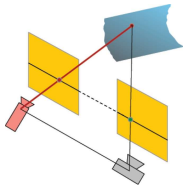
Variants to light spot

- Pattern projection
  - project a pattern instead of a single point
  - needs only a single image, one-shot recording
  - ...but matching is no longer unique (although still easier)



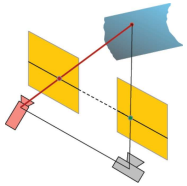
Line projection

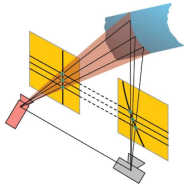
- Concept
  - A projector is just an inverse camera, ray direction is reversed.
  - The projector is described by the same geometric model.
  - Projected pattern and image define two rays in space.
    - One projector and one camera are sufficient for triangulation.



Calibrated Projection

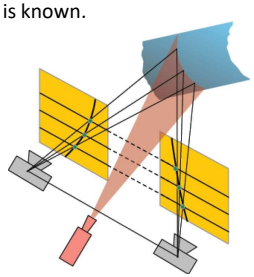
- Projector-camera system must be calibrated
  (otherwise would not be able to triangulate)
  - The projected pattern is known.
  - Thus the depth depends only on the image point location.
  - Depth computation reduces to table-lookup.





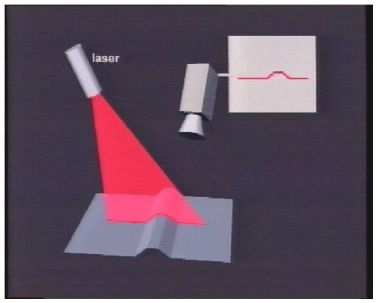
Line Projection

- Observation
  - For a calibrated camera rig, the epipolar geometry is known.
  - System can project a line instead of a single point.
  - A lot fewer images needed (one for all points on a line).
  - Line intersects each epipolar line in one point
  - … matching is still unique.



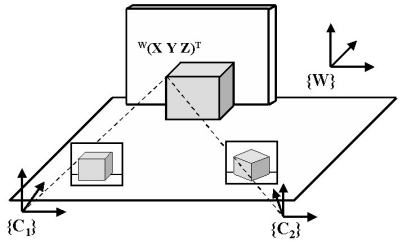
Active stereo: Example

- ***Active manipulation of scene:*** Project light pattern on object.
- Observe geometry of pattern via 3D camera geometry.



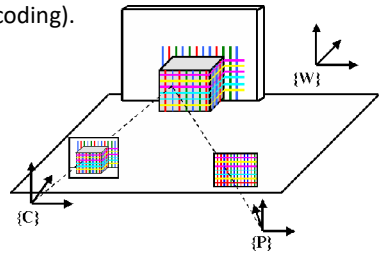
Passive triangulation: Stereo vision

- Keypoints detection in the images
- Correspondence problem
- Geometric constraints → search along epipolar lines
- 3D reconstruction of matched pairs by triangulation



Active triangulation: Structured light

- One of the cameras is replaced by a light emitter.
- Correspondence problem is solved by searching the color pattern in the camera image (pattern decoding).
- No geometric constraints.



Active stereo: General Setup

- (At least) one camera
- (At least) one light source
  - Types
    - slide projector
    - Laser
  - Projection
    - Spot
    - Stripe
    - pattern

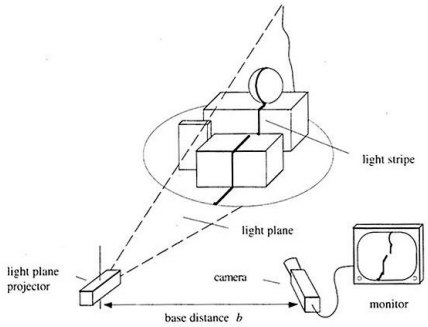
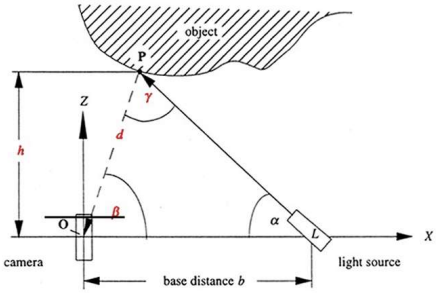


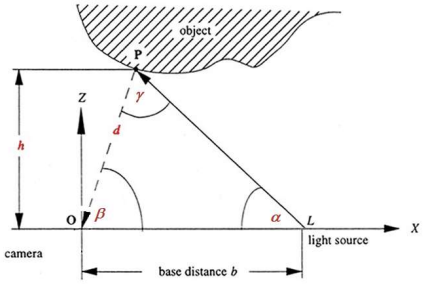
Image acquisition set-up for the light stripe projection technique.

Light Spot Projection 2D



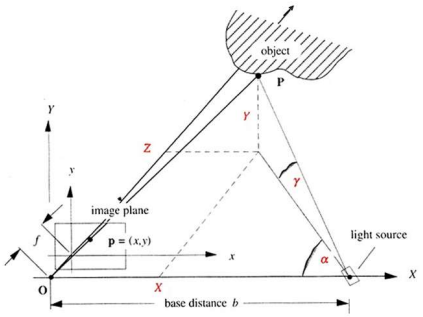
Assume point-wise illumination by laser beam, only 2D (XZ-plane).

Light Spot Projection 2D

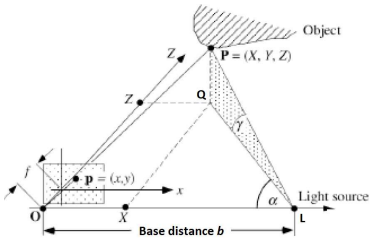


- *O*, *L* and *P* defines a triangle.
- Using *law of sines*:
  $\frac{d}{\sin(\alpha)} = \frac{b}{\sin(\gamma)} = \frac{b}{\sin(\pi - (\alpha + \beta))}$
- The distance $d = b\frac{\sin(\alpha)}{\sin(\alpha+\beta)}$
- Known b, α and image coord. x
- Angle $\beta = tan^{-1}\left(\frac{x}{f}\right)$
- Calculate d
- Height $h = d\cos\left(\frac{\pi}{2} - \beta\right)$

Light Spot Projection 3D

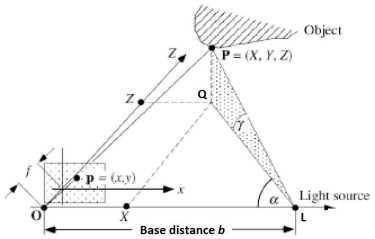


Light Spot Projection 3D



- In QXL triangle, QX perp. XL implies
$$\tan\alpha = \frac{Z}{b-X}$$
- From perspective projection
$$x = f\frac{X}{Z} \text{ and } y = f\frac{Y}{Z}$$
- It follows that
$$Z = f\frac{X}{x} = (b-X)\tan\alpha$$
$$\Rightarrow X(\frac{f}{x} + \tan\alpha) = b\tan\alpha$$
$$\Rightarrow X = \frac{xb\tan\alpha}{f + x\tan\alpha}$$

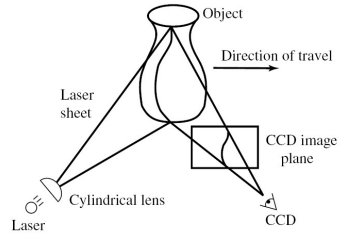
Light Spot Projection 3D



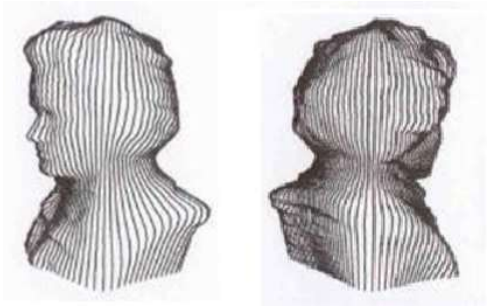
- Thus to summarize:
  - $X = \frac{xb\tan\alpha}{f+x\tan\alpha}$
  - $Y = \frac{yb\tan}{f+x\,\mathrm{ta}}$
  - $z = \frac{fb\tan}{f+x\tan\alpha}$

Single light stripe and rotating Object

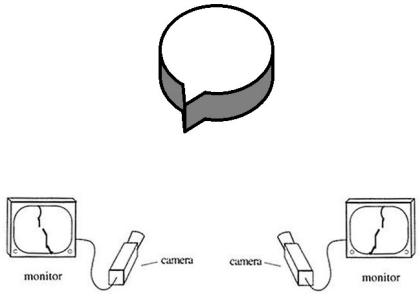
- Object on turntable:
  - Rotate object in discrete intervals and repeat
  - Create P(X,Y,Z) profile for each rotation and fixed light slit
  - Reconstruct 3D object by cylindric assembly of profiles → 3D mesh
- Very accurate
- Time consuming



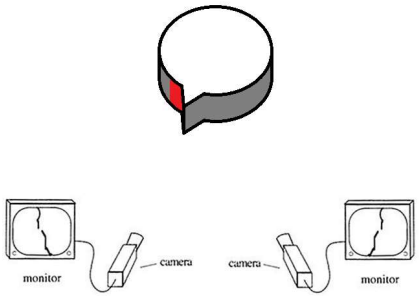
Single light stripe and rotating Object



Occlusion



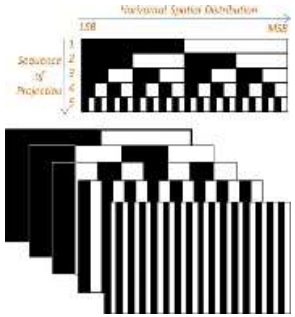
Occlusion



Occlusion and correspondence problem

- Some parts of the object may be self-occluded.
  - May be seen by one camera, not the other.
- Makes correspondence problem more difficult.
- Unique binary number may be assigned to every point of surface.
  - Binary numbers are defined by (dark, light) pattern.
- Correspondence between points in two image planes may be established by matching binary patterns.

Occlusion and correspondence problem



Thank you !

Any question?