Updates to some TSBB21 lectures 2022

Maria Magnusson, 8/12 2022

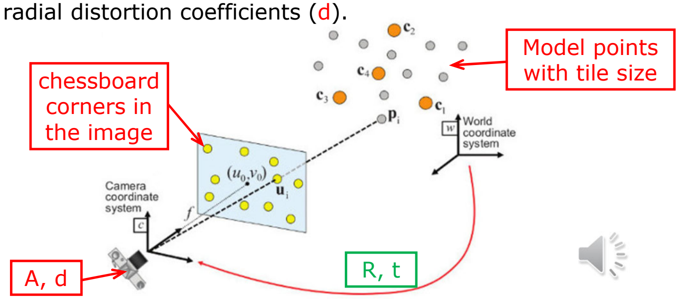
Camera Calibration 2

Perspective-n-Point (PnP) pose computation

- The pose computation problem consists in solving for the rotation and translation that minimizes the reprojection error from 3D-2D point correspondences.
- We used OpenCV:s solvePnP in the Camera calibration lab 2.

Perspective-n-Point (PnP) pose computation

- OpenCV:s solvePnP and related functions estimate the object pose (R, t) given a set of object points (For us: model points with tile size), their corresponding image projections (For us: chessboard corners detected in the image), as well as the camera intrinsic matrix (A) and the radial distortion coefficients (d).



Perspective-n-Point (PnP) pose computation

$$\begin{bmatrix}u\\v\\1\end{bmatrix} = \begin{bmatrix}f_x&0&c_x\\0&f_y&c_y\\0&0&1\end{bmatrix}\xcancel{\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\end{bmatrix}}\begin{bmatrix}r_{11}&r_{12}&r_{13}&t_x\\r_{21}&r_{22}&r_{23}&t_y\\r_{31}&r_{32}&r_{33}&t_z\\\cancel{0}&\cancel{0}&\cancel{0}&\cancel{1}\end{bmatrix}\begin{bmatrix}X_w\\Y_w\\Z_w\\1\end{bmatrix}$$

chessboard corners in the image

A

C

R,t

Model points with tile size

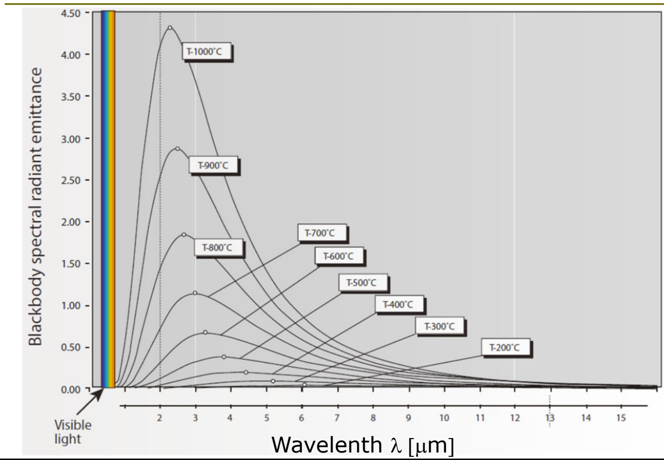
- We can solve C, given the model points with tile size and the corresponding chessboard corners in the image. This is similar to the calibration of a flat world that we did with the potato stick in Camera Calibration lab 1.
- We can then solve R and t from C and A.

Perspective-n-Point (PnP) pose computation

- The equation on the previous slide was simplified. The radial distortion d should be included also. However, OpenCV:s solvePnP can deal with this.
- Changing the size of the chessboard tiles will change the output translation vector t. However, this will not affect the projection of the model. The reprojection errors will not be affected. Also, R will be correct.

Planck's and Stefan-Boltzmann's laws

Repetition: Planck's law



The relation between Planck's and Stefan-Boltzmann's laws

- According to Planck's law, the spectral emittance of a blackbody is: $$M(\lambda,T) = \frac{2\pi hc^2}{\lambda^5(e^{hc/\lambda kT}-1)}$$
- It can be shown that the integral over Planck's law for all wavelengths of a blackbody gives that the total radiated energy is: $$W = \sigma T^4 \; [W/m^2],$$

  where σ is the Stefan-Boltzmann's constant. (It is not so easy to perform the integration!)
- For a greybody, $W = \varepsilon\sigma T^4 \; [W/m^2]$,

  where ε is the emissivity.

Range camera updates

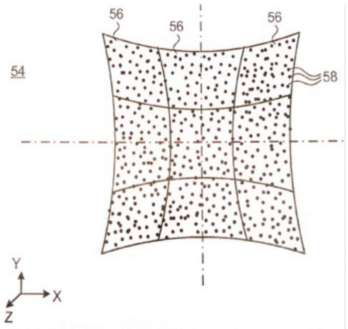
Repetition & update: Different range camera principles

- I) Triangulation and passive stereo
- II) Active light and triangulation
  - a) "Single spot" with triangulation
  - b) "Sheet-of-light" with triangulation
  - c) "Structured light" with triangulation
    - c1) Simple grid pattern
    - c2) Binary or Gray-coded patterns
    - c3) Microsoft Kinect 1 (Random dot pattern)
    - c4) Fringe patterns
- III) Time-of-flight
  - a) Light pulse and time measurement, LIDAR (light+RADAR)
  - b) Time-of-flight camera. Amplitude modulated light.
    - Sinusoidal wave and phase shift measurement
    - "Rectangular" pulse. Measure three short intervals. (Also called Flash LIDAR, which is a confusing name.)

- i) Stationary scene or moving scene
- ii) Scanning or stationary light

Repetition: Microsoft Kinect 1 with structured light and random dot pattern

- The dot pattern is designed to have as low an autocorrelation as possible:
  - for all shifts larger than the point size and …
  - in the interval of disparities that the system needs to deal with, i.e. along the base-line.
  - Corresponding points are received by correlation with pattern patches.
  - Depth is then received from triangulation.
  - Reduced detail resolution due to the correlation with pattern patches.

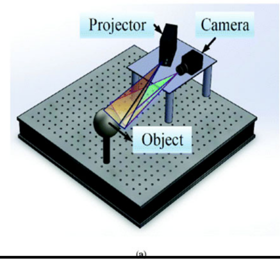


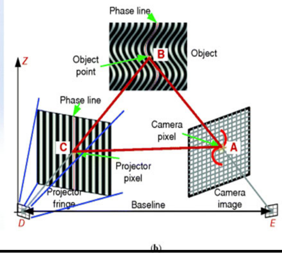
Random dot patterns videos

- https://www.youtube.com/watch?v=CIkscN6nXcE
- https://www.youtube.com/watch?v=uq9SEJxZiUg

"Structured light" with triangulation

- From https://onlinelibrary.wiley.com/doi/full/10.1002/047134608X.W8298
- There are many types of structured patterns (e.g. a simple grid pattern, binary patterns, or Gray-coded patterns.
- Left: illustration of a structured light system containing one projector, one camera, and an object to be captured.
- Right: schematic diagram of a 3D structured light imaging system using fringe pattern projection



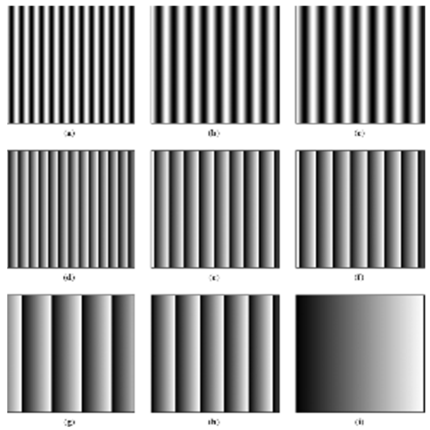


Sinusoidal patterns = Fringe patterns

- With sinusoidal patterns, pixel-level resolution is possible as intensities vary across the image from point to point at known frequencies and therefore can be differentiated.
- The figure shows 3 sinusoidal patterns with different wavelengths.
- Instead of using intensity values to establish correspondence, phase information is used. One benefit of this is an inherent robustness to surface texture variation.
- Three or more fringe images must be used if robust and accurate measurements are desired.

Multifrequency phase-shifting method

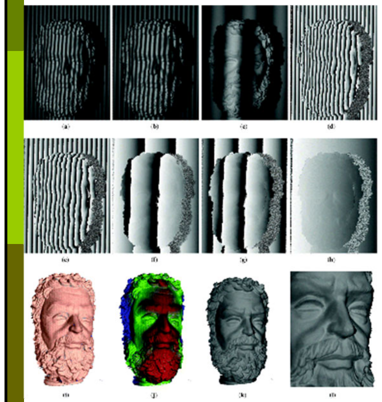
optional!



- (a) One fringe pattern ($\lambda 1$ = 60 pixels).
- (b) One fringe pattern ($\lambda 2$ = 90 pixels).
- (c) One fringe pattern ($\lambda 3$ = 102 pixels).
- (d) Wrapped phase $\varphi 1$.
- (e) Wrapped phase $\varphi 2$.
- (f) Wrapped phase $\varphi 3$.
- (g) Equivalent phase difference $\Delta\varphi 12$.
- (h) Equivalent phase difference $\Delta\varphi 13$.
- (i) Resultant phase $\Delta\varphi 123$ that can be used to eventually unwrap $\varphi 1$.

details
not required

Example of 3D frame capture



- (a) One fringe pattern (λ1 = 30 pixels).
- (b) One fringe pattern (λ2 = 36 pixels).
- (c) One fringe pattern (λ3 = 231 pixels)
- (d) Wrapped phase φ1.
- (e) Wrapped phase φ2.
- (f) Wrapped phase φ3.
- (g) Equivalent phase difference Δφ12.
- (h) Equivalent phase difference Δφ123 that can be used to unwrap φ1.
- (i) Reconstructed 3D data from the unwrapped φ1 with the application of calibration parameters to recover world coordinates.
- (j) The 3D results colored based on depth value.
- (k) 3D results with texture mapping applied.
- (l) Zoomed-in view.