Pose Tracking I

CS 6334 Virtual Reality

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A lot of slides of course lectures borrowed from Professor Yu Xiang's VR class

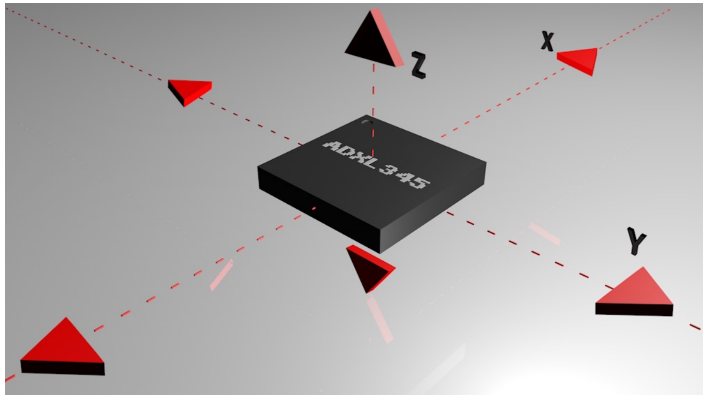
Tracking in VR

- Tracking the user's sense organs
  - E.g., Head and eye
  - Render stimulus accordingly

- Tracking user's other body parts
  - E.g., human body and hands
  - Locomotion and manipulation
- Tracking the rest of the environment
  - Augmented reality
  - Obstacle avoidance in the real world

Tracking 3D Orientation and 3D Position

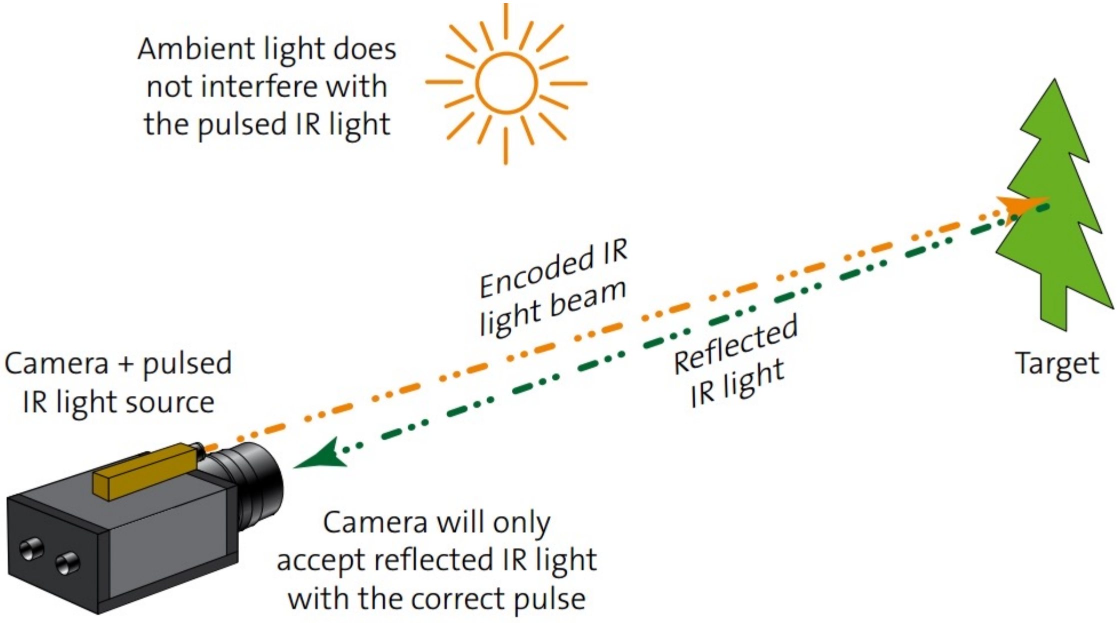
- Why not just integrate the accelerometer?
  - Drift error, quadratically growing with calibration error (difference between true value and the measured value)
  - The true body acceleration cannot be accurately extracted, especially when the body quickly rotates
  - IMU itself cannot help
    - Cannot even distinguish motions at constant velocity



Wave-based Tracking

- Active tracking systems
  - Infrared, ultrasound, and electromagnetic fields

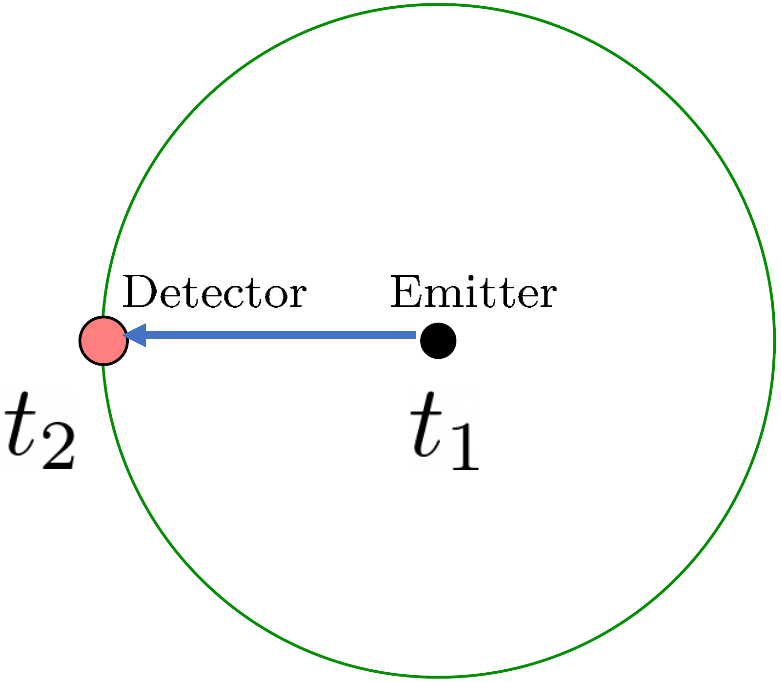
- Emitter-detector pair
  - Speaker-microphone
  - Time of flight to estimate distance



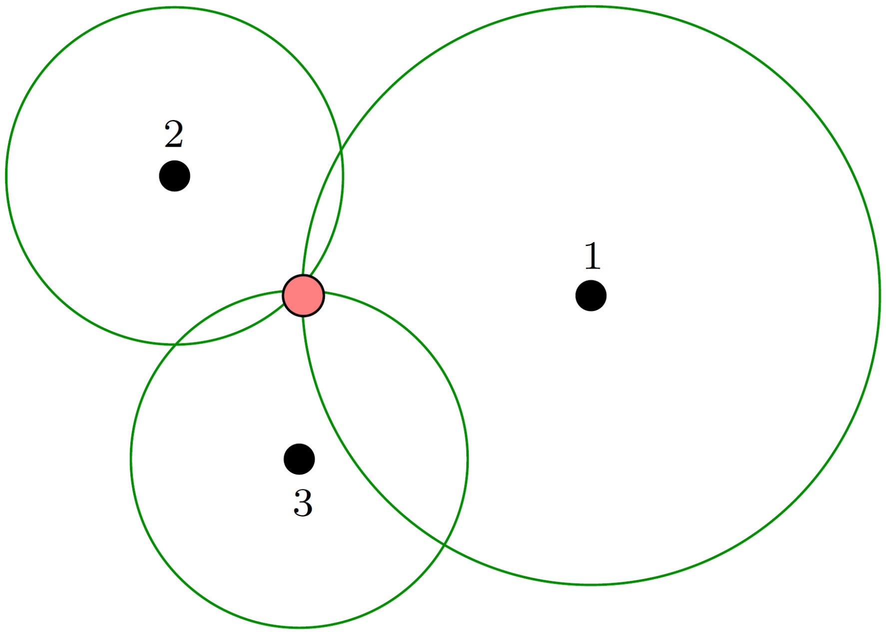
https://www.stemmer-imaging.com/en-ie/knowledge-base/cameras-3d-time-of-flight-cameras/

Wave-based Tracking

- Trilateration



Three emitters



Time measurement is synchronized between source and destination
Use time of arrival (time of flight) to compute distance

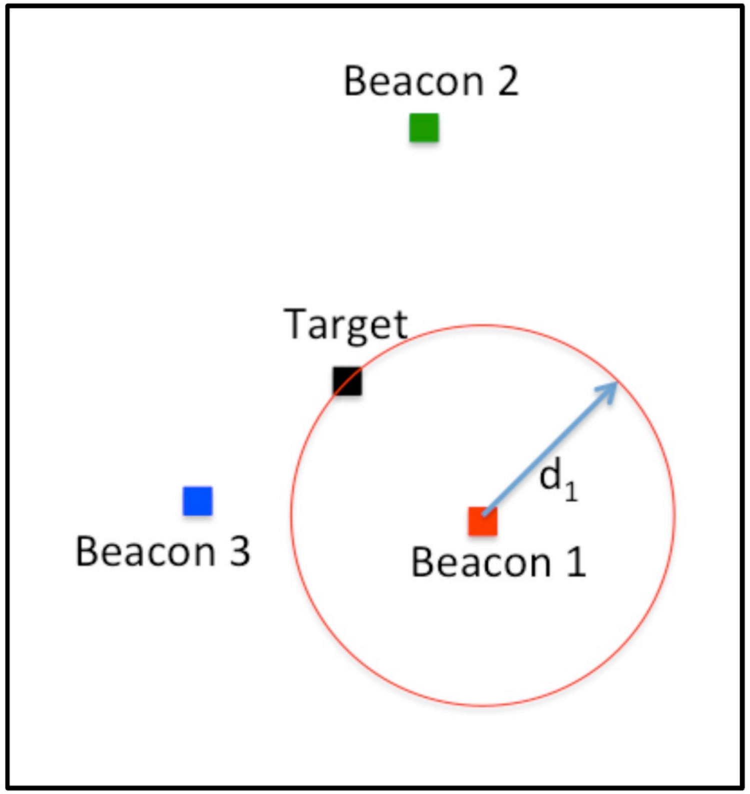
- 330 m/s for ultrasound

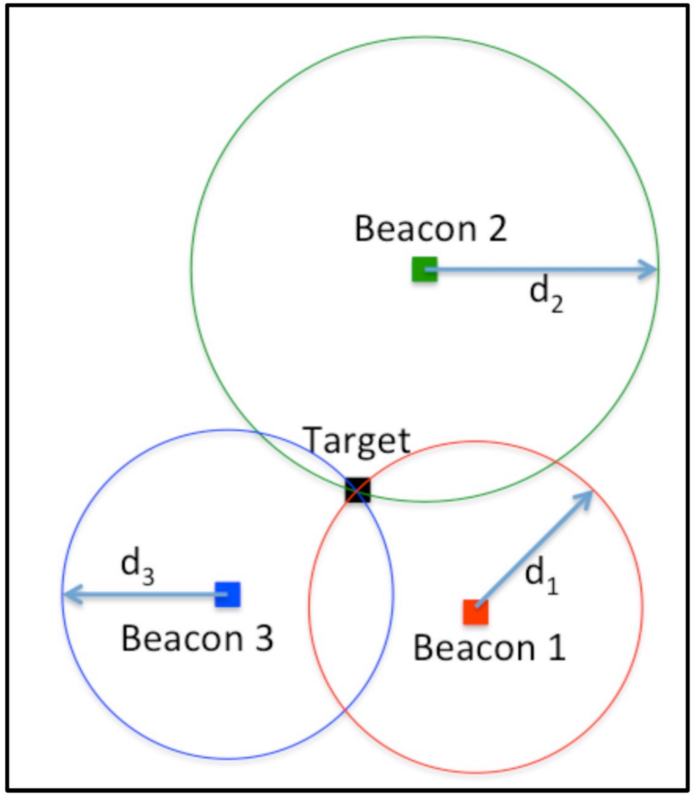
Time of Arrival (ToA)

- Signals sent from a beacon to the target
- Known sending time and arrival time

$$d = c * (t_{arrival} - t_{sent})$$

$$d = \sqrt{(x_{ref} - x)^2 + (y_{ref} - y)^2}$$





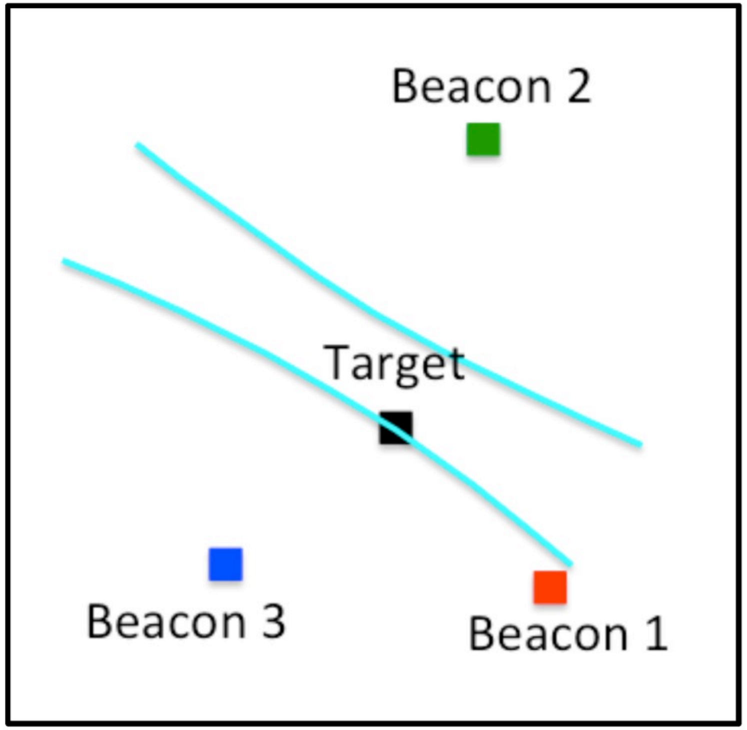
https://sites.tufts.edu/eeseniordesignhandbook/files/2017/05/FireBrick_OKeefe_F1.pdf

Time Difference of Arrival (TDoA)

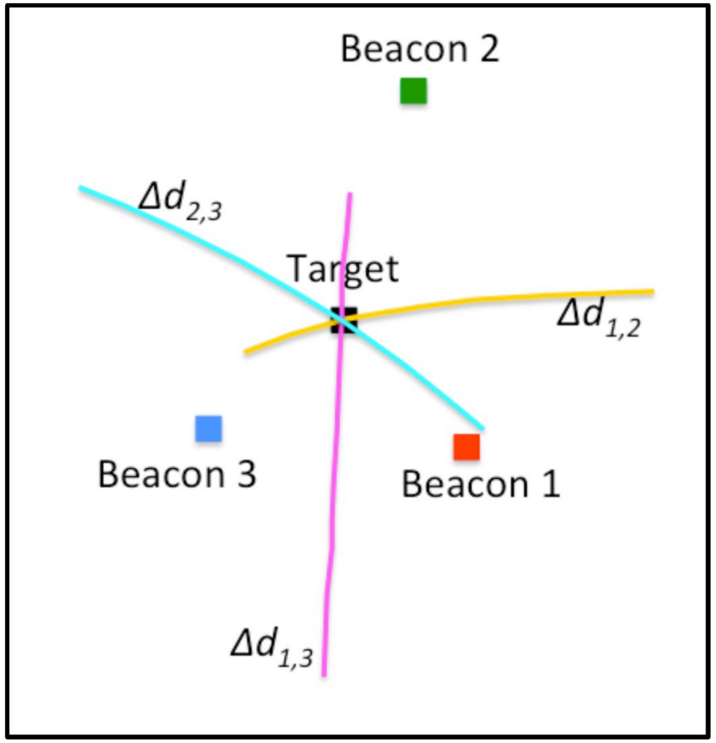
- Do not know sending time
- Signals sent from the target to beacons

$$\Delta d = c * (\Delta t)$$

$$\Delta d = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} - \sqrt{(x_1 - x)^2 + (y_1 - y)^2}$$



hyperbola



https://sites.tufts.edu/eeseniordesignhandbook/files/2017/05/FireBrick_OKeefe_F1.pdf

Wave-based Tracking

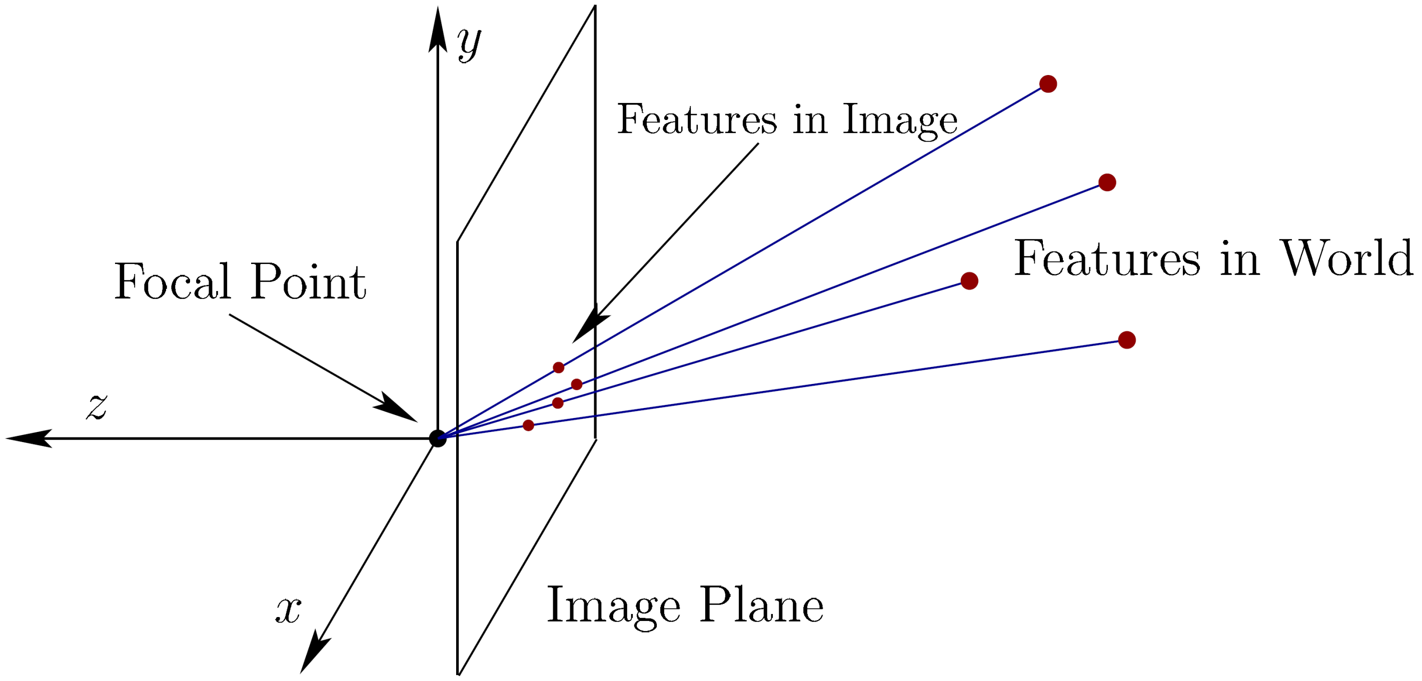
- Magnetic fields
  - The field should vary greatly across different locations
  - Drawback: the field may become unpredictably warped in each environment, causing straight-line motions to be estimated as curved

(a) (b)

Figure 9.10: (a) A magnetic dipole offers a field that varies its magnitude and direction as the position changes (figure by Wikipedia user Geek3). (b) The Razer Hydra, a game controller system that generates a weak magnetic field using a base station, enabling it to track the controller positions (figure by http://www.GamingShogun.com/).

Feature-based Tracking

- Using visibility of features in the real world



- Natural Features
  - No setup cost
  - A difficult computer vision problem
- Artificial features
  - Print a special tag

QR code

QR Code (Quick Response Code)

- QR codes contains more information than barcodes

7,089 numeric characters or 2,953 alphanumeric characters

20 to 100 characters

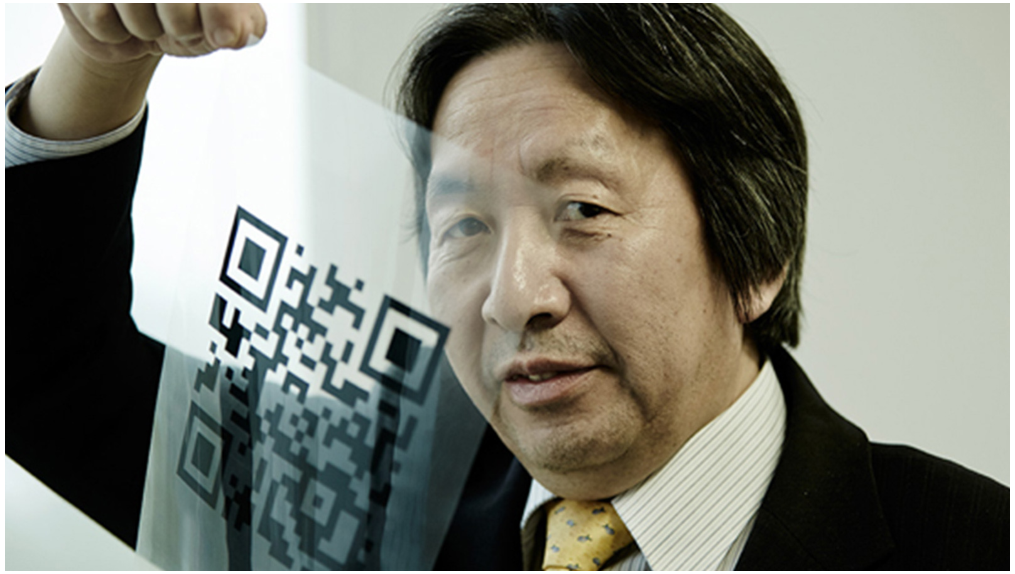
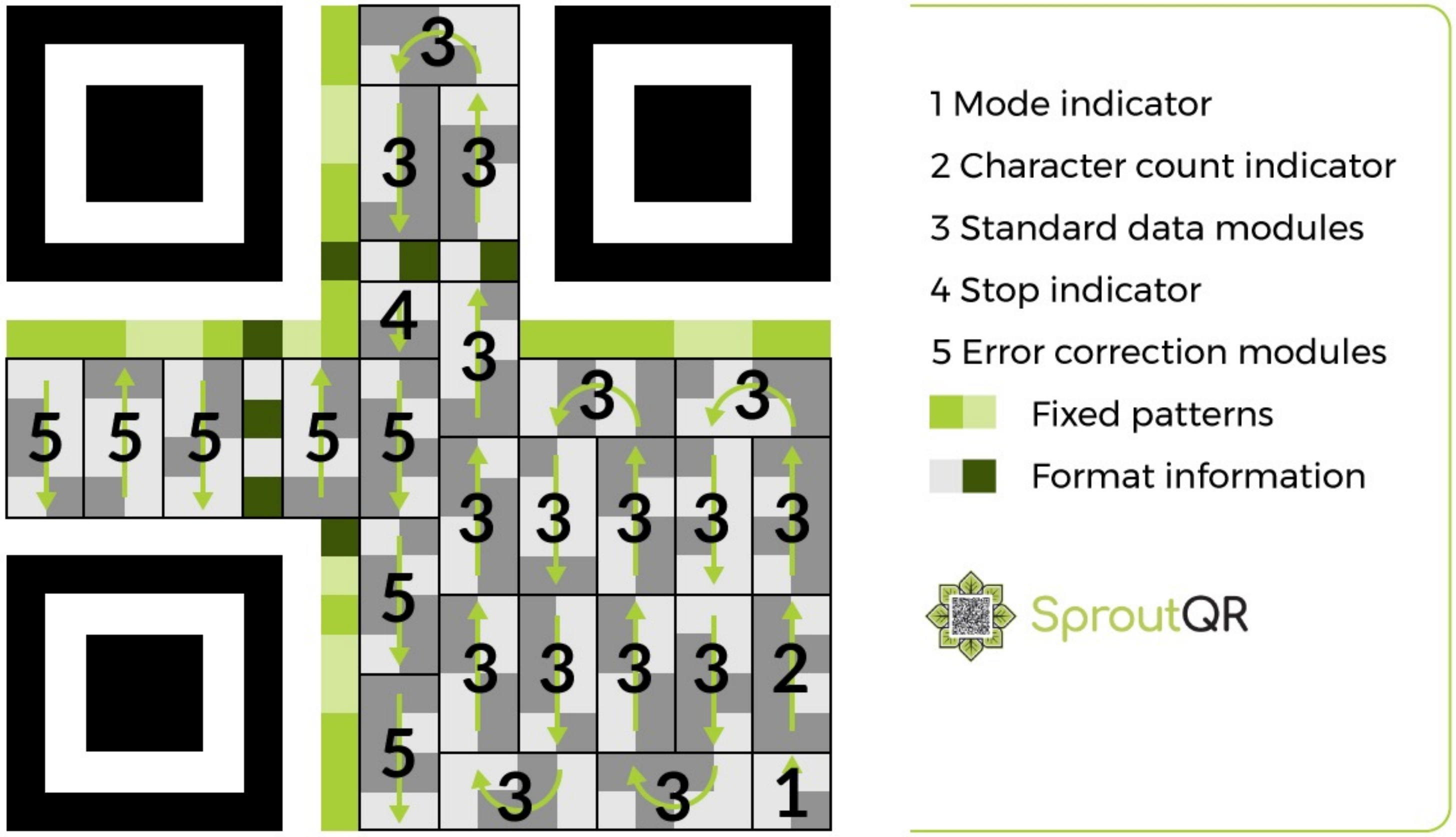


Photo of QR Code inventor Masahiro Hara. Source: qrcode.com

DENSO WAVE

QR Code



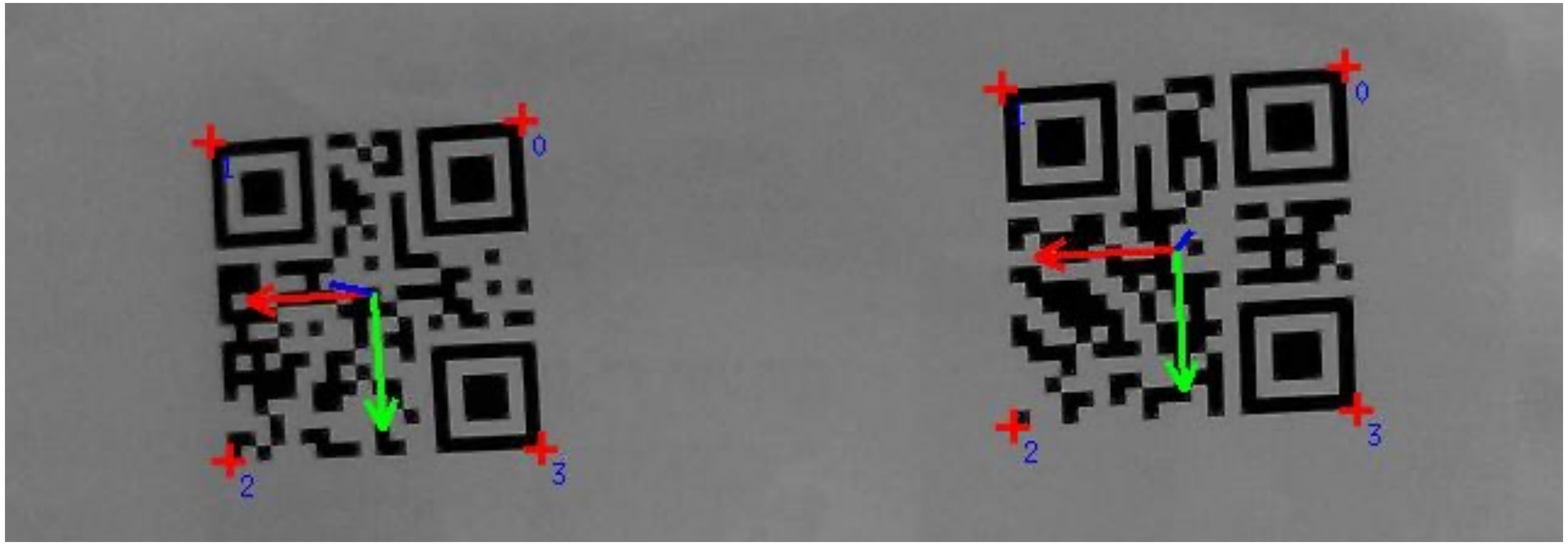
Mode type: numeric, alphanumeric, byte, or kanji (Japanese)

Data is stored in bits

- e.g., 01011011

QR Code for Pose Estimation

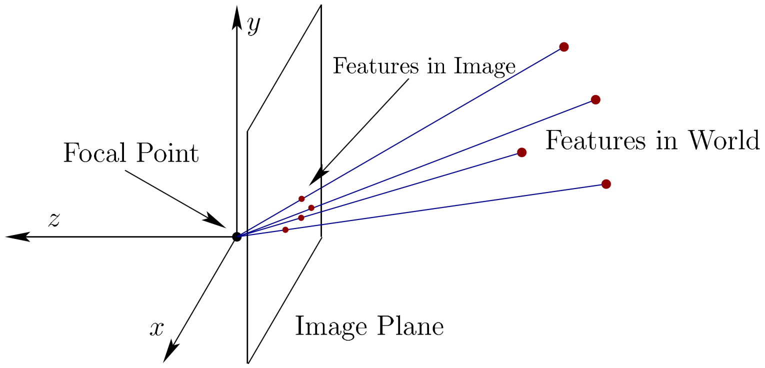
- Using the 4 corners of a QR code as features



https://visp-doc.inria.fr/doxygen/visp-daily/tutorial-pose-estimation-qrcode.html

The Perspective-n-Point (PnP) Problem

- Given/known variables
  - A set of n 3D points in the world coordinates p_w
  - Their projections (2D coordinates) on an image p_c
  - Camera intrinsics K
- Unknown variables
  - 3D rotation of the camera with respective to the world coordinates R
  - 3D translation of the camera T

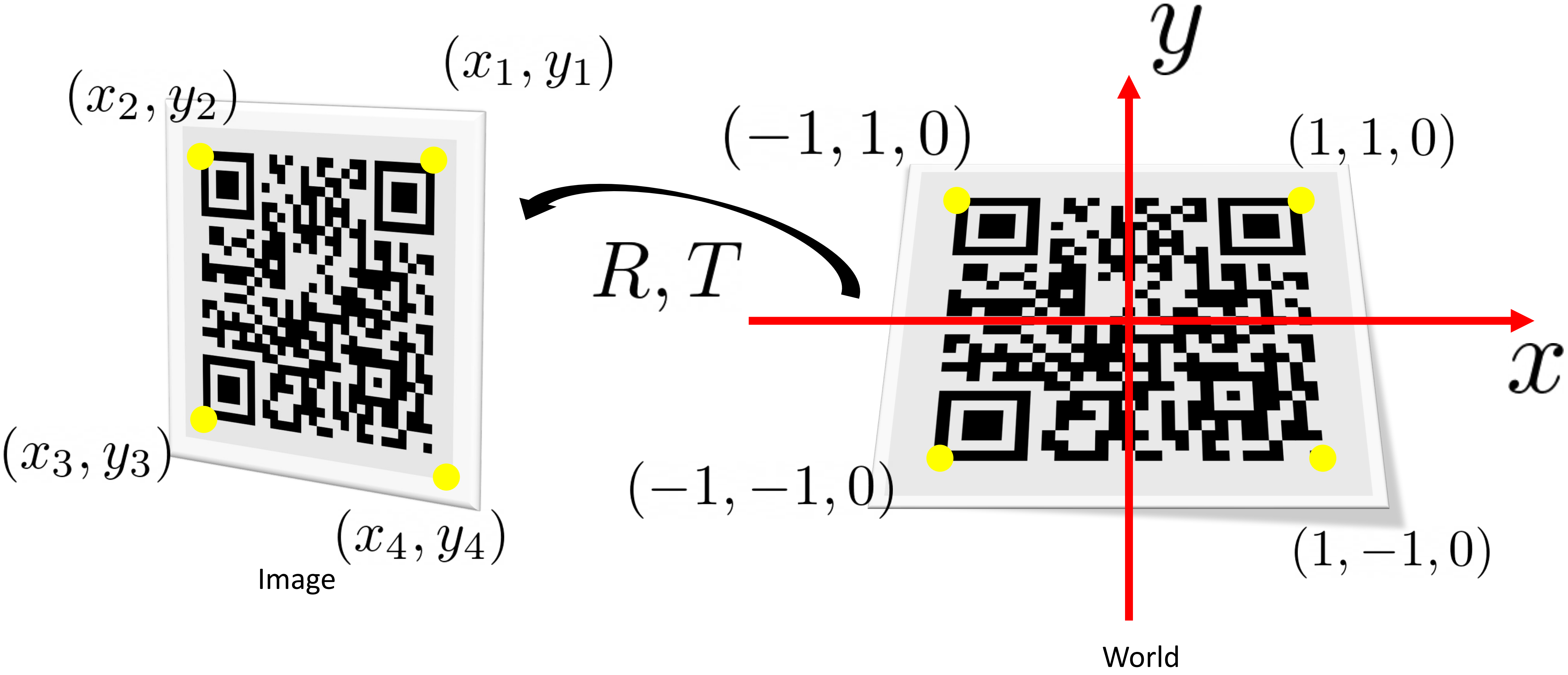


$$s\,p_c = K\,[\,R\,|\,T\,]\,p_w$$

Unknown

$$s\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & \gamma & u_0 \\ 0 & f_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

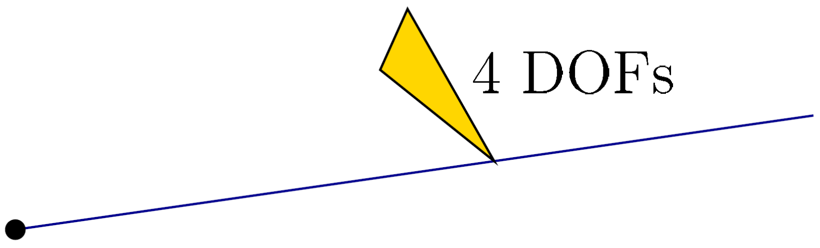
The PnP Problem with QR Code



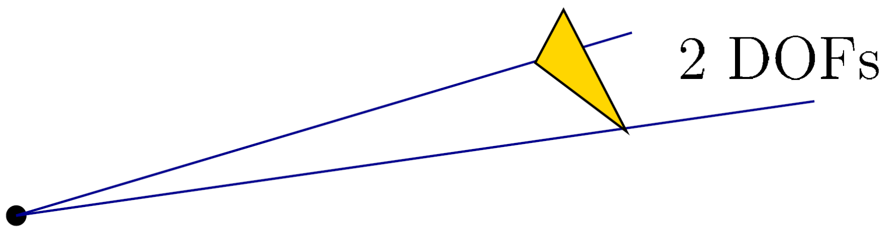
The Perspective-n-Point (PnP) Problem

- 6 degrees of freedom (DOFs)
  - 3 DOF rotation, 3 DOF translation

- Each feature that is visible eliminates 2 DOFs

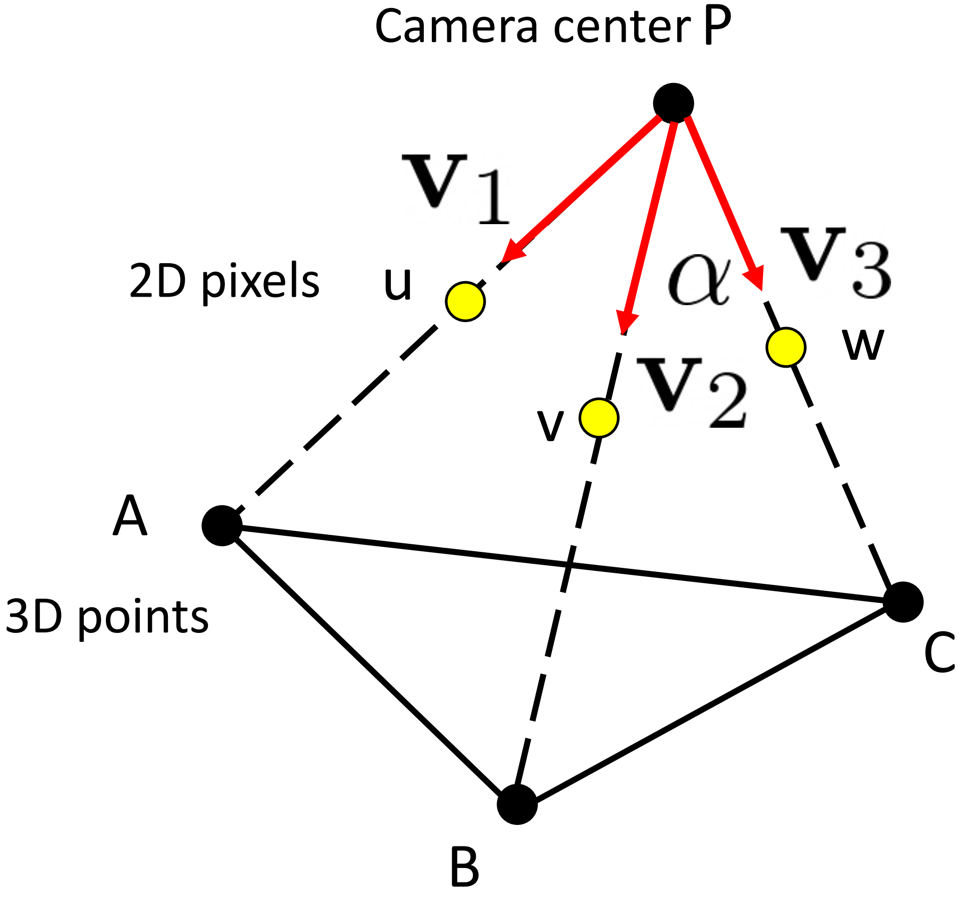


P1P



P2P

P3P



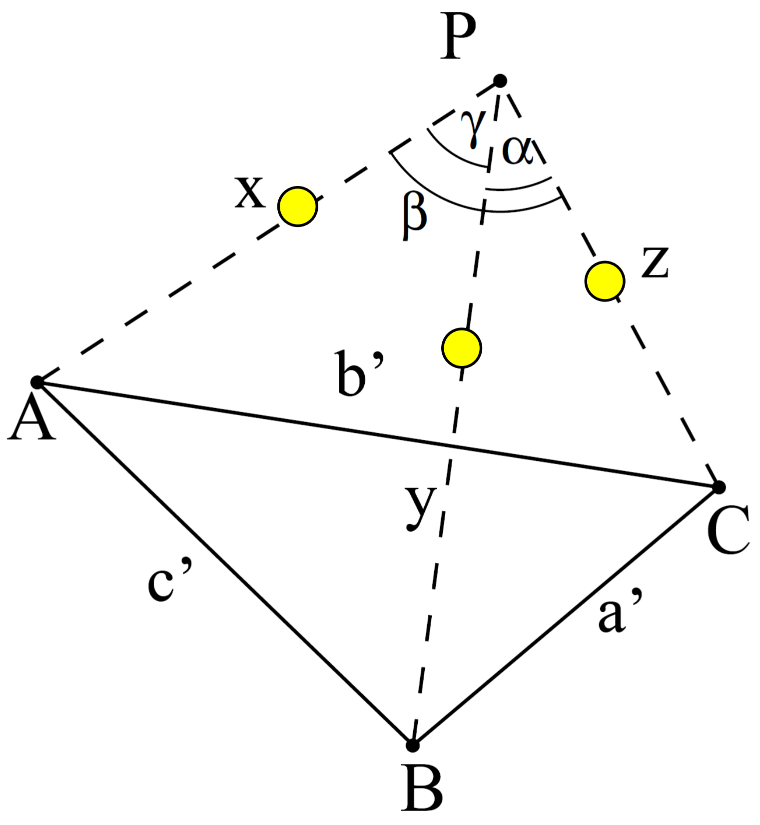
$$\mathbf{v}_1 = K^{-1}\mathbf{u}$$

$$\mathbf{v}_2 = K^{-1}\mathbf{v}$$

$$\mathbf{v}_3 = K^{-1}\mathbf{w}$$

$$\mathbf{v}_2 \cdot \mathbf{v}_3 = \|\mathbf{v}_2\| \|\mathbf{v}_3\| \cos\alpha$$

P3P



$$X = |PA| \quad Y = |PB| \quad Z = |PC|$$

$$p = 2\cos\alpha \qquad a' = |BC|$$

$$q = 2\cos\beta \qquad b' = |AC|$$

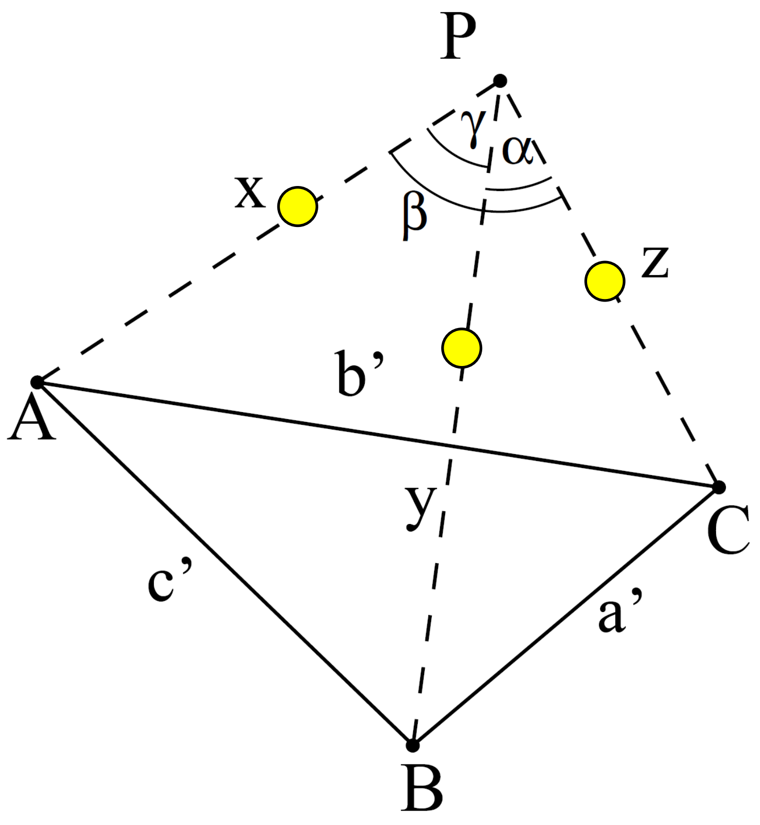
$$r = 2\cos\gamma \qquad c' = |AB|$$

law of cosines

$$\begin{cases} Y^2 + Z^2 - YZp - a'^2 = 0 \\ Z^2 + X^2 - XZq - b'^2 = 0 \\ X^2 + Y^2 - XYr - c'^2 = 0. \end{cases}$$

X, Y, Z are the unknowns

P3P



- Find the solutions for X, Y, Z (depth of the 3 pixels)
- Obtain the coordinates of A, B, C in camera frame
- Compute R and T using the coordinates of A, B, C in camera frame and in world frame

6D Pose Between Two Sets of 3D Points

- A well-studied problem
- Least-squares Estimation

$$\sum^2 = \sum_{i=1}^{N} ||X_{cam}^i - (RX_w^i + T)||^2$$

K.S. Arun, T.S. Huang, and S.D. Blostein. Least-Squares Fitting of Two 3-D Points Sets. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 9(5):698–700, 1987.

S. Umeyama. Least-squares estimation of transformation parameters between two point patterns. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 13(4), April 1991

Further Reading

- Section 9.3, Virtual Reality, Steven LaValle