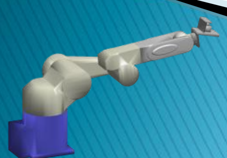
VISUAL SERVOING (Background)

- Lecture Notes: Teresa Vidal Calleja



Servo-mechanism

- Automatic device that uses feedback of the error between the desired and actual position of a mechanism to drive the device to the desired position

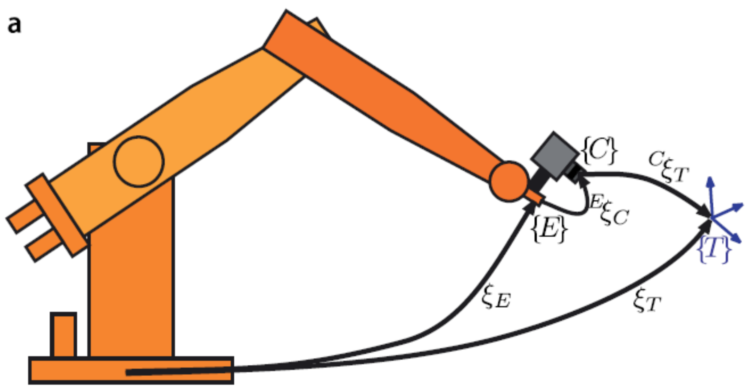
https://www.youtube.com/watch?v=bf2GvyEKQQo

Visual servoing

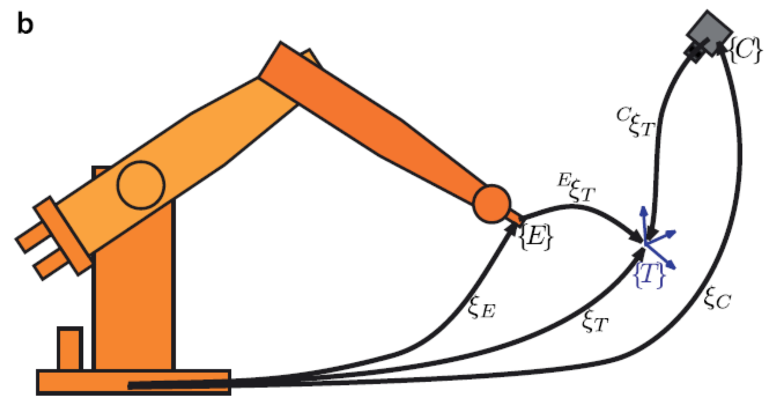
VS is used to control the pose of the robot’s end-effector, relative to a target, using visual features extracted from the image

https://www.youtube.com/watch?v=TZXmyrLRPqc&t=4s

Visual servoing configurations



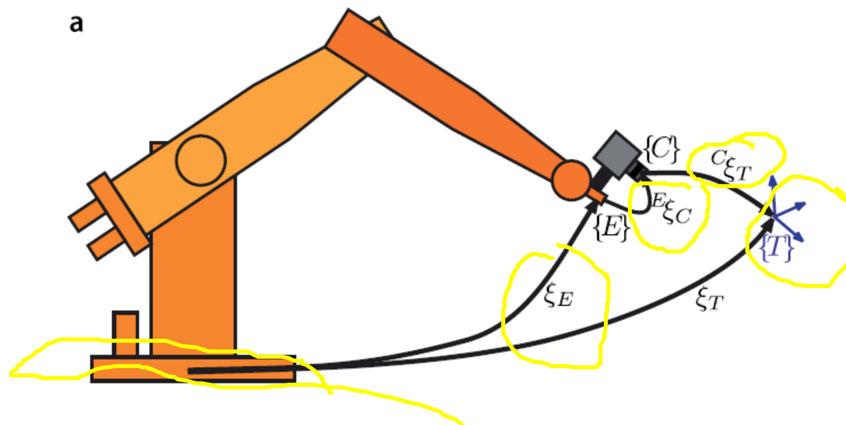
End-point closed-loop
(Eye-in-hand)



End-point open-loop
(Eye-to-hand)

Notation

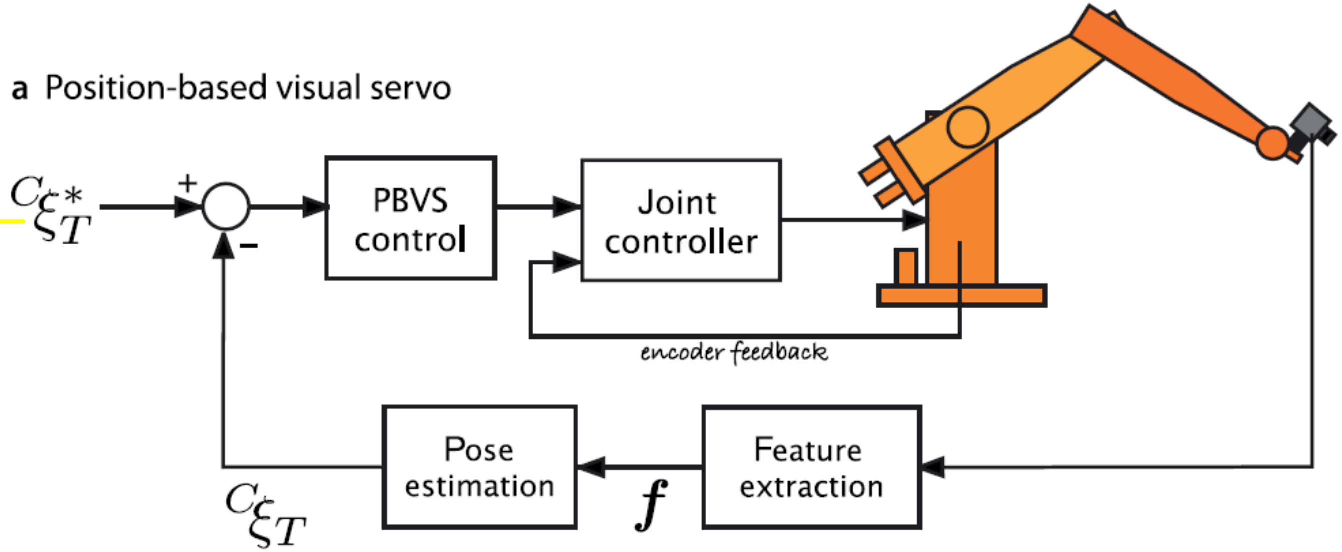
- Coordinate frames:
  - World (Base)
  - End-effector $\{E\}$
  - Camera $\{C\}$
  - Target $\{T\}$



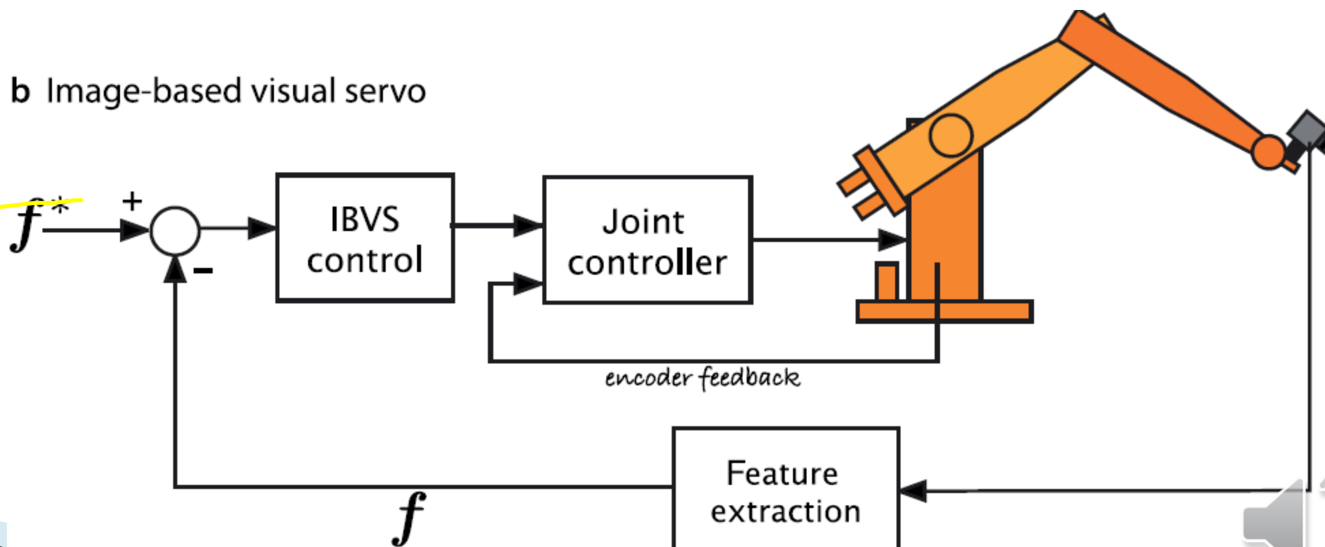
- Image of target is a function of the relative pose ${}^{C}\xi_{T}$

Main Approaches

- PBVS



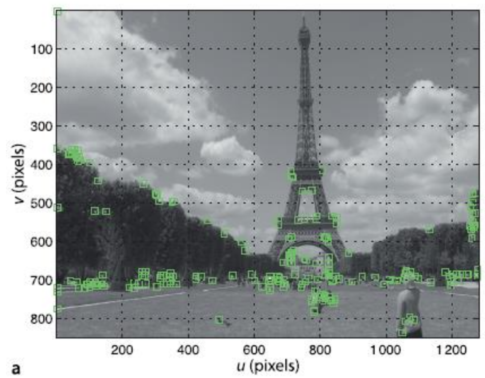
- IBVS



Visual Features

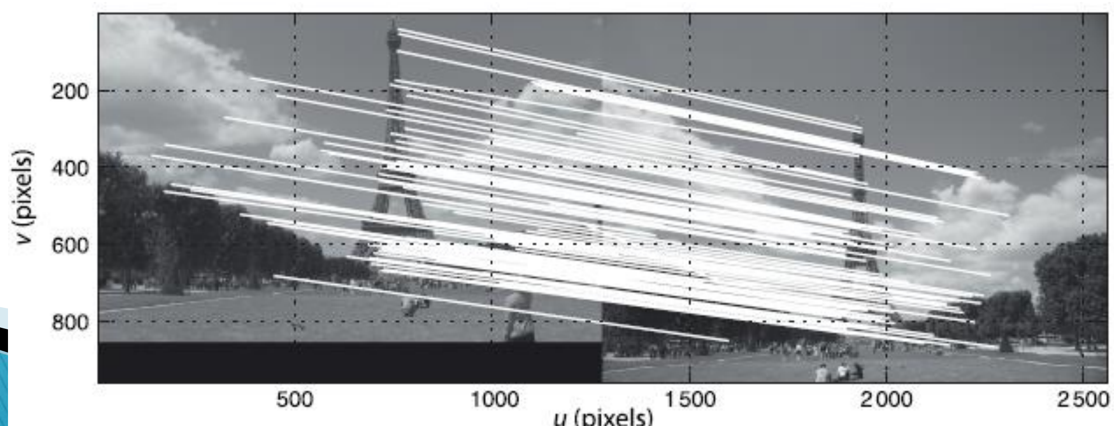
Requires image processing

- Extract relevant information from the image

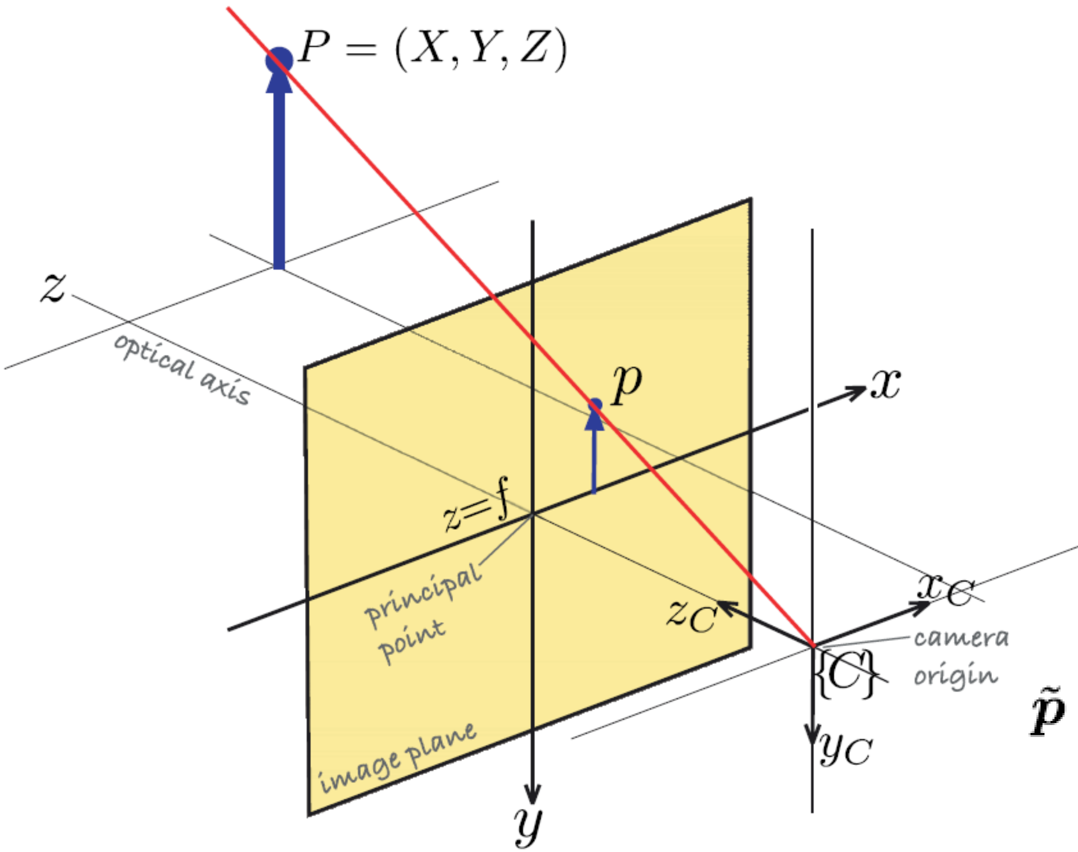


a

- Track over consecutive frames



Central-projection camera model



$$^{C}\tilde{\boldsymbol{P}} = (X, Y, Z, 1)^T$$

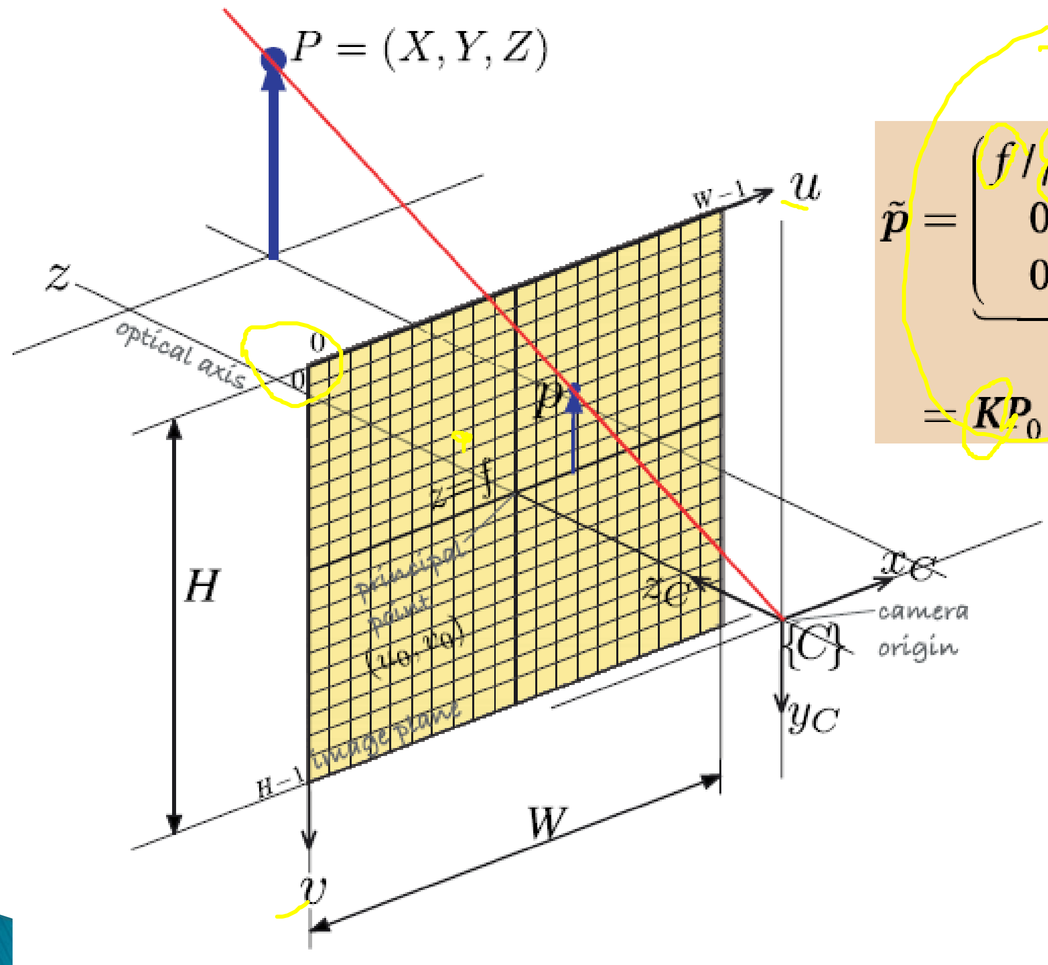
$$x = f\frac{X}{Z},\ y = f\frac{Y}{Z}$$

$$\tilde{\boldsymbol{p}} = \begin{pmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$\tilde{\boldsymbol{p}} = \underbrace{\begin{pmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\boldsymbol{K}} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} {}^{C}\tilde{\boldsymbol{P}}$$

$\boldsymbol{K}$ Camera Calibration Matrix

Central-projection camera model

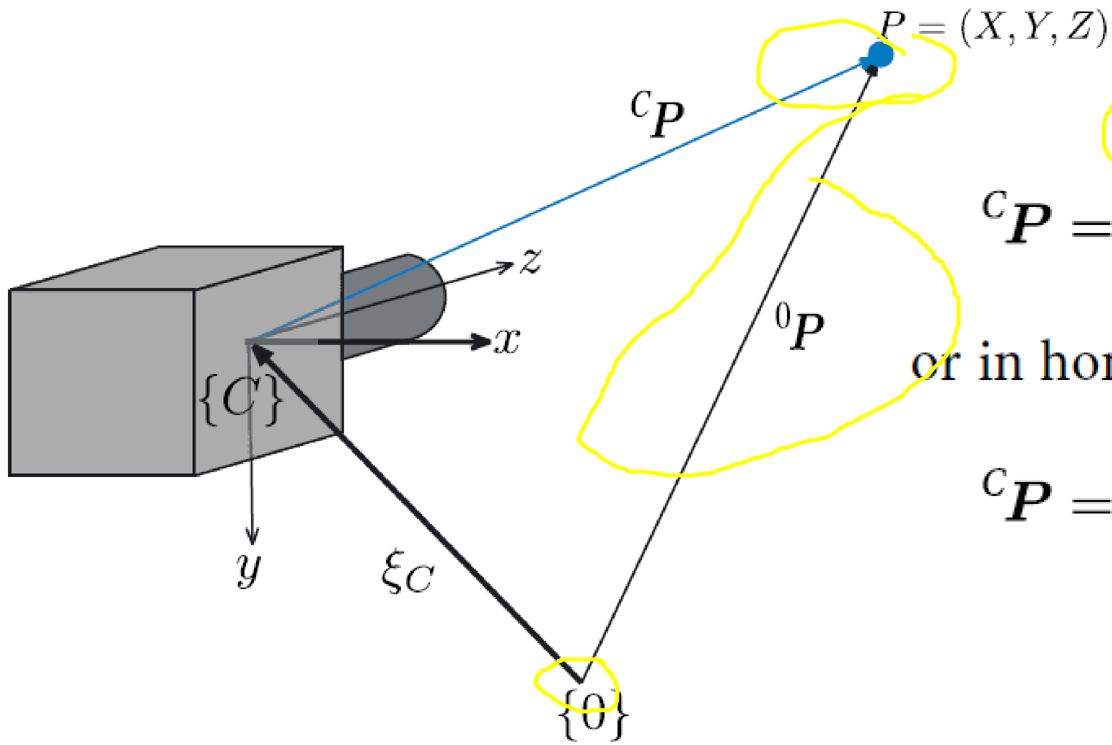


$$\tilde{p} = \underbrace{\begin{pmatrix} f/\rho_w & 0 & u_0 \\ 0 & f/\rho_h & v_0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}}_{\text{intrinsic}} \underbrace{({}^{0}\mathbf{T}_C)^{-1}}_{\text{extrinsic}} \tilde{\boldsymbol{P}}$$

$$= \boldsymbol{K}\boldsymbol{P}_0 \, {}^{0}\boldsymbol{T}_C^{-1} \tilde{\boldsymbol{P}}$$

Camera Calibration Matrix accounting for pixels and principal point (u0,v0)

Camera Coordinate frames



$${}^{C}\boldsymbol{P} = (\ominus \xi_C) \bullet {}^{0}\boldsymbol{P}$$

or in homogeneous coordinates

$${}^{C}\boldsymbol{P} = \boldsymbol{T}_C^{-1}\, {}^{0}\boldsymbol{P}$$

Projection is a function of

$$\boldsymbol{p} = \mathcal{P}(\boldsymbol{P}, \boldsymbol{K}, \xi_C)$$

if $\xi_C = I$

$$u = \frac{f}{\rho_u}\frac{X}{Z} + u_0,\ v = \frac{f}{\rho_v}\frac{Y}{Z} + v_0$$

Further Info

- Peter Corke's Robotics, Vision and Control

- Other sources

https://www.coursera.org/learn/robotics-perception/lecture/wKcXj/pinhole-camera-model