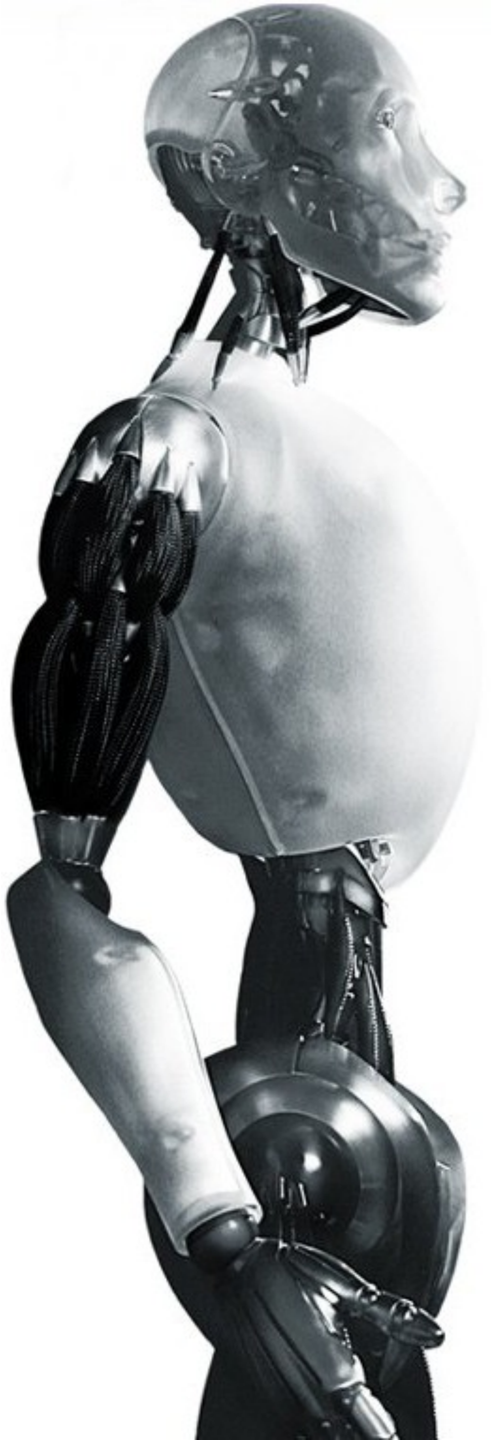
Disclaimer

These slides are intended as presentation aids for the lecture. They contain information that would otherwise be to difficult or time-consuming to reproduce on the board. But they are incomplete, not self-explanatory, and are not always used in the order they appear in this presentation. As a result, these slides should not be used as a script for this course. I recommend you take notes during class, maybe on the slides themselves. It has been shown that taking notes improves learning success.

Reading for this set of slides

- There is no reading for this set of slides. Please refer to the reading about Jacobians. We only cover very basic concepts of computer vision and the Web is a fine resource for this.

Please note that this set of slides is intended as support for the lecture, not as a stand-alone script. If you want to study for this course, please use these slides in conjunction with the indicated chapters in the text books. The textbooks are available online or in the TUB library (many copies that can be checked out for the entire semester. There are also some aspects of the lectures that will not be covered in the text books but can still be part of the homework or exam. For those It is important that you attend class or ask somebody about what was covered in class.

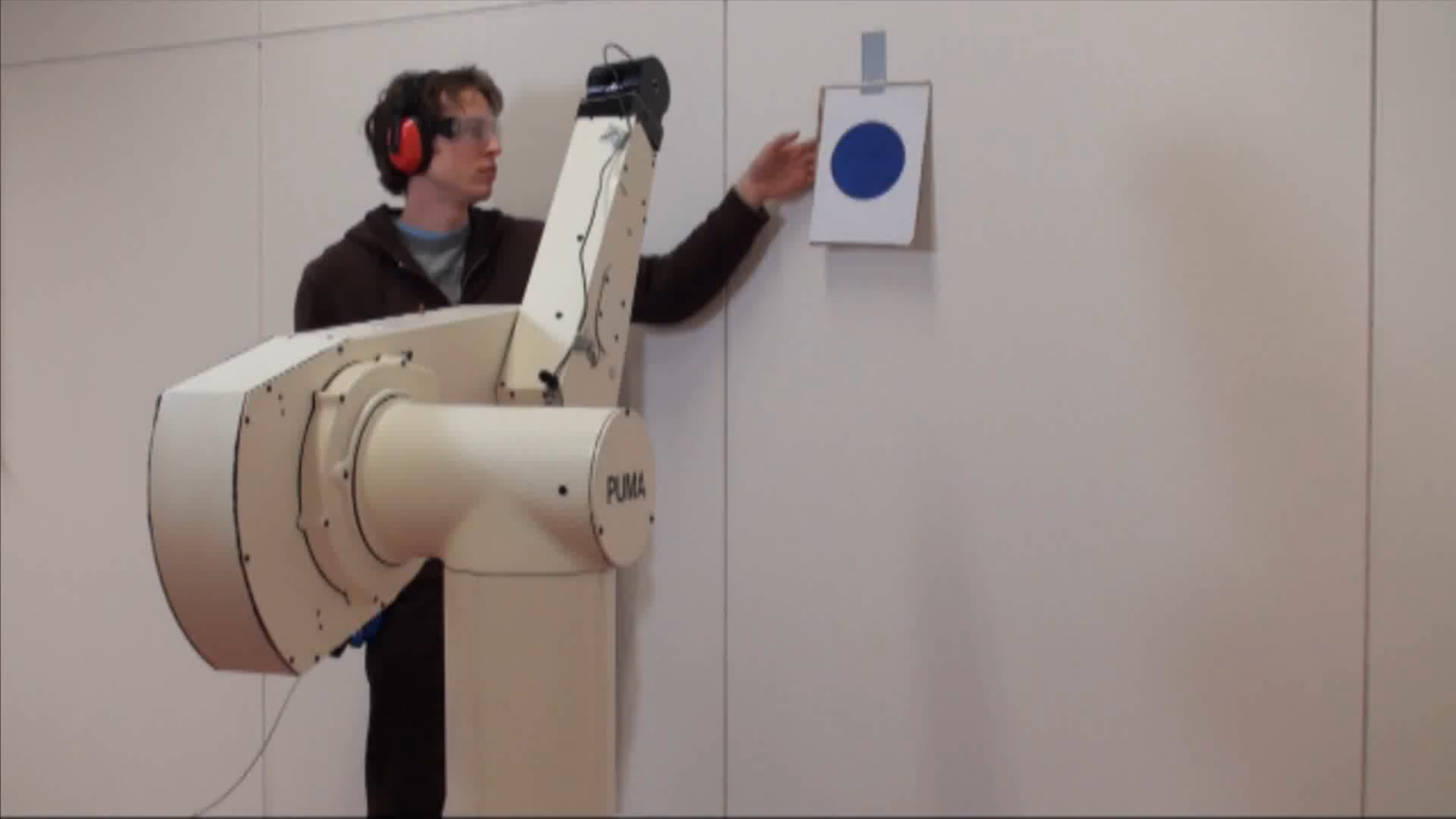


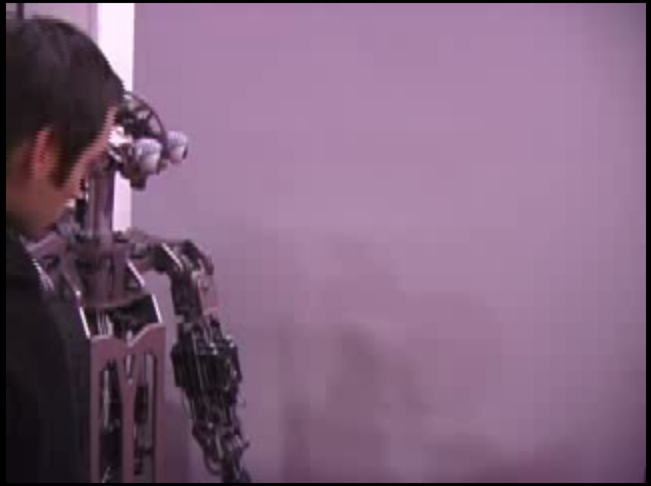
Robotics

Computer Vision & Visual Servoing

TU Berlin

Oliver Brock


PUMA

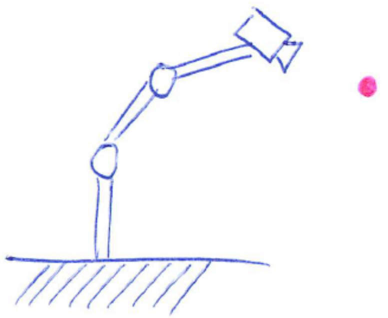


What do we need for Visual Servoing?

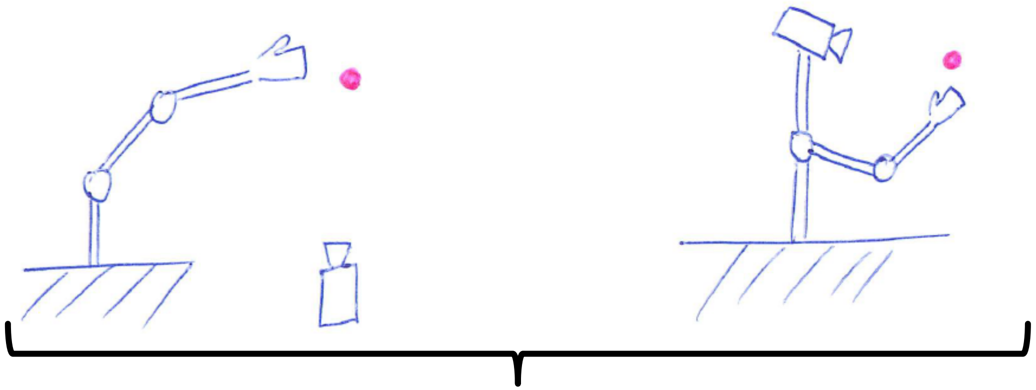
- Vision
- Servoing
- (Of course)

Visual Servo Control (Visual Servoing)

- Using visual feedback to control the motion of the robot



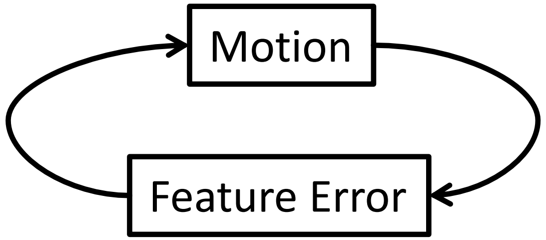
eye-in-hand system

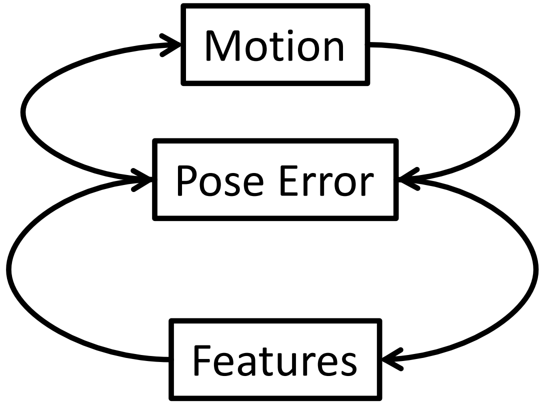


eye-to-hand system

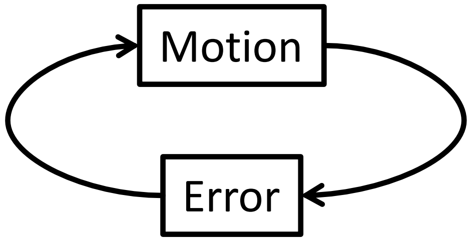
endpoint closed-loop (ECL)
or
endpoint open-loop (EOL)

Image-based versus Position-based

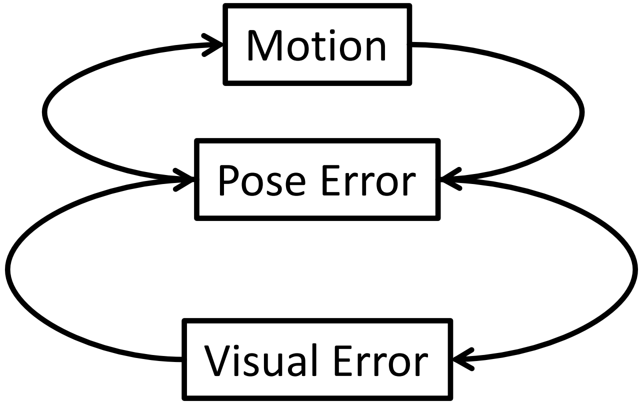




Direct Visual Servo versus Dynamic Look-and-Move



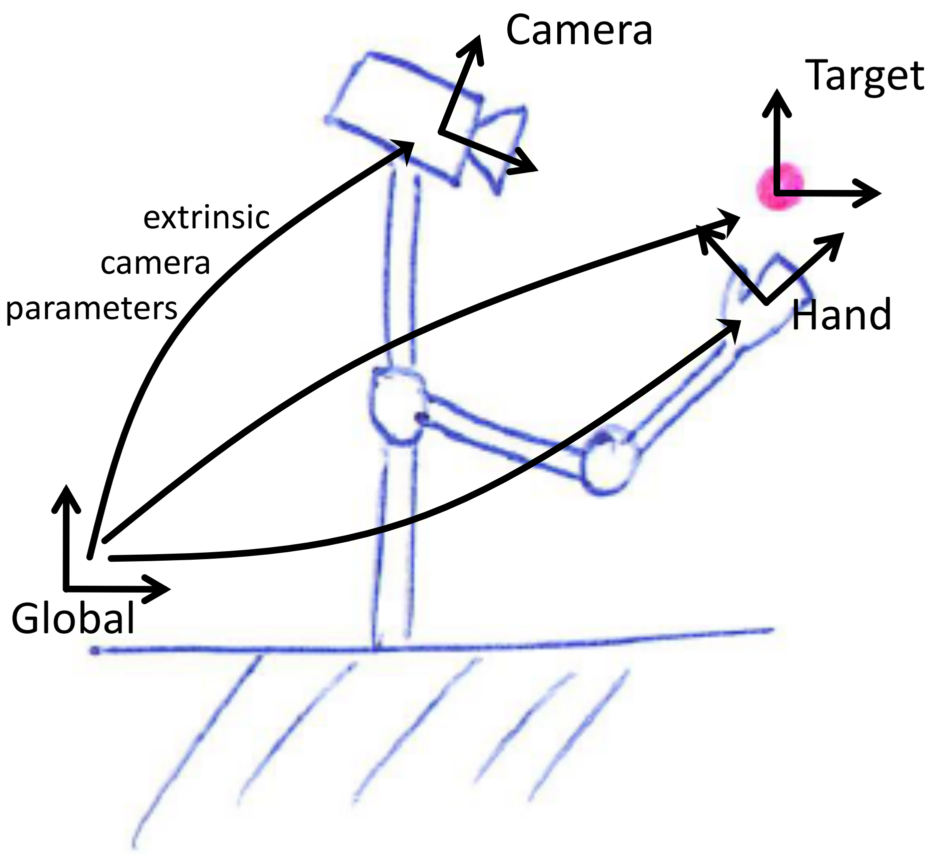
All in one servo loop



High-frequency motion loop

Low-frequency vision loop

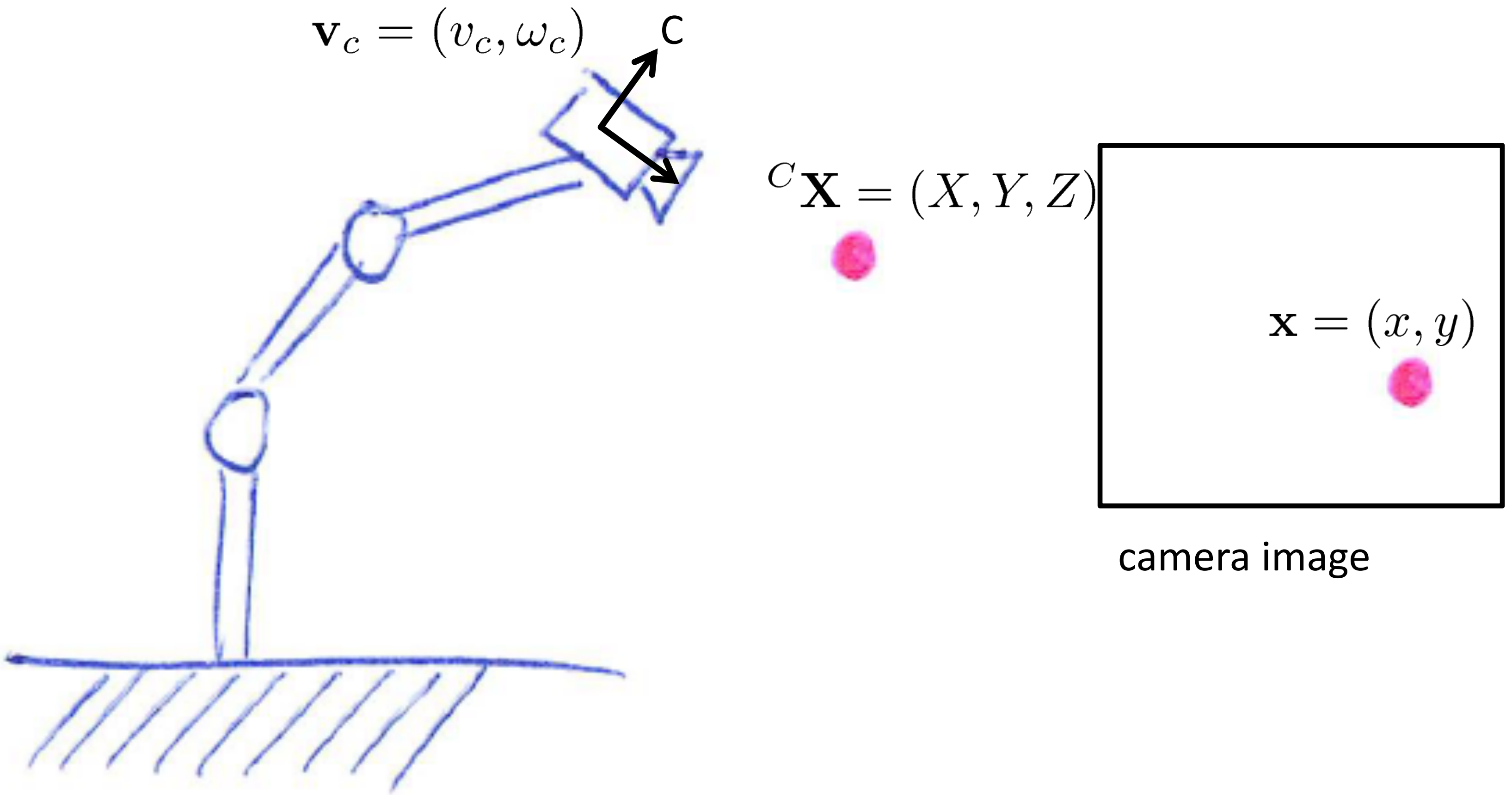
Frames and Parameters



Intrinsic parameters

- focal length
- center of image plane
- axis scaling
- distortion
- pixel size
- ...

How to servo? (image-based)



Servo to center the target in the image!

Key: Image Jacobian

$$\dot{\mathbf{s}} = J_I \mathbf{v}_c$$

velocities of image features camera velocity

$\mathbf{s}$ vector of image features

$$J^+ = (J^T J)^{-1} J^T$$

$$\mathbf{e}(t) = \mathbf{s} - \mathbf{s}_{\mathrm{des}}$$

$$\dot{\mathbf{e}} = J_I \mathbf{v}_c$$

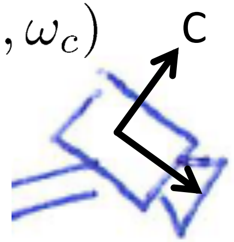
$$\mathbf{v}_c = -\lambda J^{-1} \mathbf{e}$$

with $\dot{\mathbf{e}} = -\lambda \mathbf{e}$

$$\mathbf{v}_c = -\lambda J^{+} \mathbf{e}$$

Image Jacobian/Interaction Matrix

$\mathbf{v}_c = (v_c, \omega_c)$



${}^{C}\mathbf{X} = (X, Y, Z)$

$\mathbf{x} = (x, y)$

$\mathbf{m} = (u, v)$

$$\begin{aligned} x &= X/Z = (u - c_u)/f\alpha \\ y &= Y/Z = (v - c_v)/f, \end{aligned}$$

$$\begin{aligned} \dot{x} &= \dot{X}/Z - X\dot{Z}/Z^2 &= (\dot{X} - x\dot{Z})/Z \\ \dot{y} &= \dot{Y}/Z - Y\dot{Z}/Z^2 &= (\dot{Y} - y\dot{Z})/Z. \end{aligned}$$

$$\dot{\mathbf{X}} = -\boldsymbol{v}_c - \omega_c \times \mathbf{X} \Leftrightarrow \begin{cases} \dot{X} = -v_x - \omega_y Z + \omega_z Y \\ \dot{Y} = -v_y - \omega_z X + \omega_x Z \\ \dot{Z} = -v_z - \omega_x Y + \omega_y X. \end{cases}$$

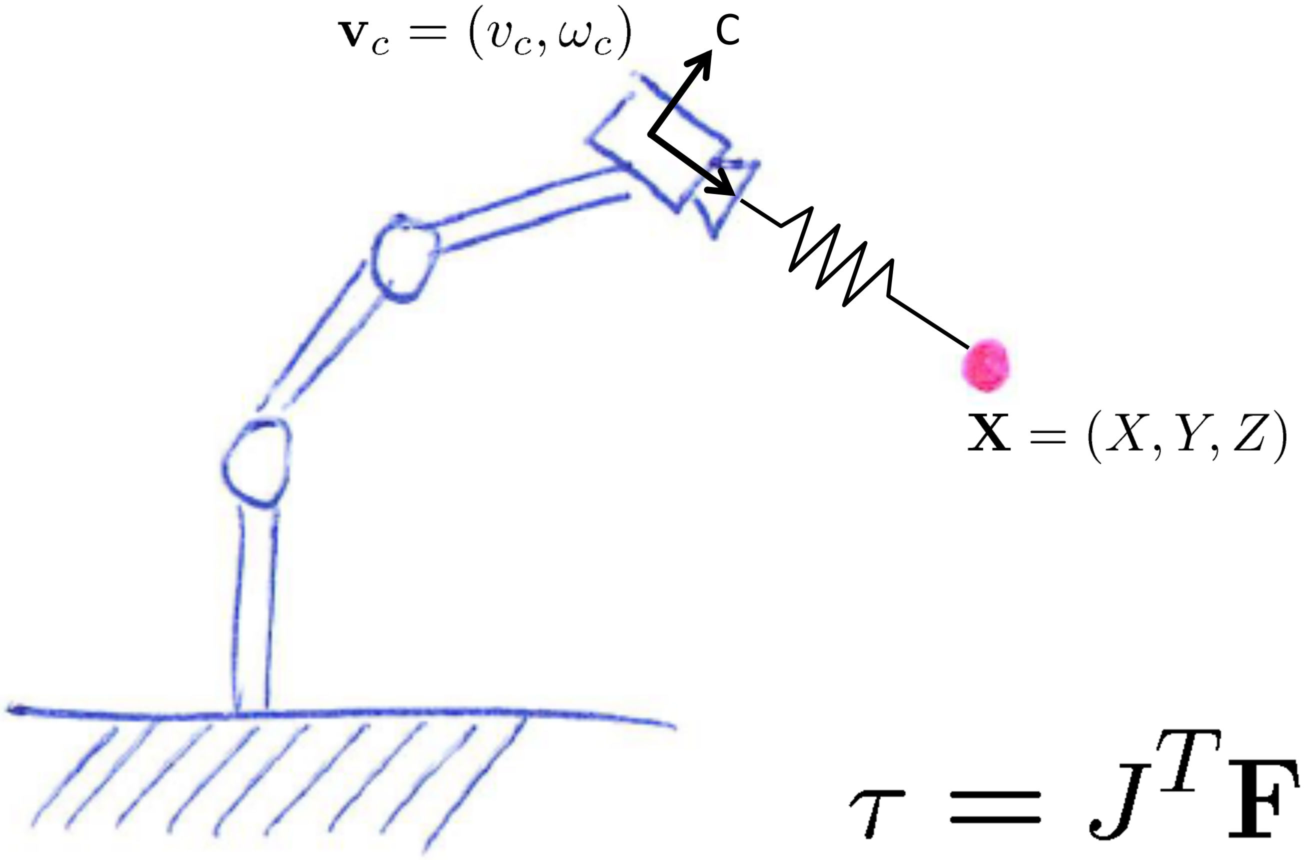
$$\begin{aligned} \dot{x} &= -v_x/Z + xv_z/Z + xy\omega_x - (1 + x^2)\omega_y + y\omega_z \\ \dot{y} &= -v_y/Z + yv_z/Z + (1 + y^2)\omega_x - xy\omega_y - x\omega_z \end{aligned}$$

$$\dot{\mathbf{x}} = \mathbf{L_x}\mathbf{v}_c \quad \mathbf{L_x} = \begin{bmatrix} \frac{-1}{Z} & 0 & \frac{x}{Z} & xy & -(1 + x^2) & y \\ 0 & \frac{-1}{Z} & \frac{y}{Z} & 1 + y^2 & -xy & -x \end{bmatrix}$$

Things to Consider

- The equations require an estimate of Z (depth)
- We need a sufficient number of image features (not a problem usually, we can simply stack the Jacobians)
- Singularities may occur

How to servo? (position-based)



$$\tau = J^T \mathbf{F}?$$