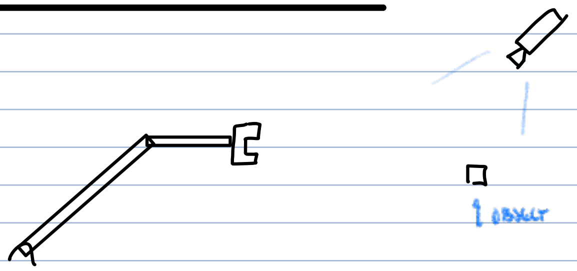
26 VISUAL SERVOING

"EYE-TO-HAND"



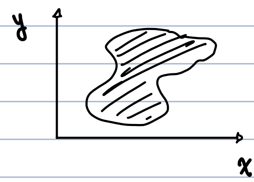
EYE-IN-HAND
- CAMERA <u>ON</u> ROBOTIC HAND

EYE-IN-HAND		VS	EYE-TO-HAND	
PROS	CONS		PROS	CONS
· NO OCCLUSIONS	· VARIABILITY IN ACCURACY · CAN'T OBSERVE END EFFECTOR		· FIELD OF VIEW + ACCURACY DON'T CHANGE	· OCCLUSIONS FROM ROBOT

IMAGE PROCESSING

1. IMAGE SEGMENTATION : RECOGNIZING OBJECT

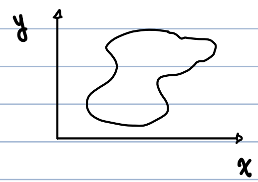
A. REGION BASED - E.G. BINARY SEGMENTATION



GRAYSCALE IMAGE
↓
APPLY THRESHOLD
↓
BINARY IMAGE

$$b(x,y) = \begin{cases} 1 & \text{OBJECT} \quad g > g_0 \\ 0 & \text{BACKGROUND} \quad g < g_0 \end{cases}$$

B. BOUNDARY-BASED (E.G. EDGE DETECTION)

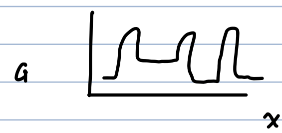


COMPUTE GRADIENT

X-GRADIENT $\Delta_1 = g(x+1,y) - g(x,y)$

y-GRADIENT $\Delta_2 = g(x,y+1) - g(x,y)$

MAGNITUDE : $G(x,y) = \sqrt{\Delta_1^2 + \Delta_2^2}$



$$b(x,y) = \begin{cases} 1 : \text{EDGE} & G > G_0 \\ 0 : \text{NO EDGE} & G < G_0 \end{cases}$$

2. IMAGE INTERPRETATION : COMPUTE FEATURE PARAMETERS

SIMPLE GEOMETRIC FEATURES:

- AREA $A = \sum_x \sum_y b(x,y)$
- CENTROID (1ST ORDER MOMENT) $x_c = \dfrac{\sum_x \sum_y x \, b(x,y)}{A}$

· 2^{ND} MOMENT OF INERTIA

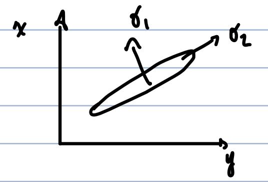
$$y_c = \frac{\sum_x \sum_y y\, b(x,y)}{A}$$

$$I_o = \begin{bmatrix} I_{xx} & I_{xy} \\ I_{xy} & I_{yy} \end{bmatrix}$$

$$I_{xx} = \sum_x \sum_y (y - y_c)^2\, b(x,y)$$

$$I_{yy} = \sum_x \sum_y (x - x_c)^2\, b(x,y)$$

$$I_{xy} = \sum_x \sum_y (x - x_c)(y - y_c)\, b(x,y)$$

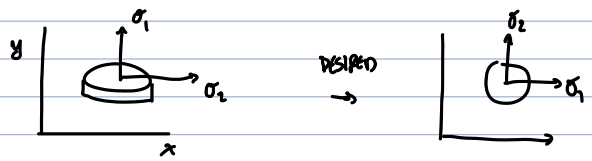


$\sigma_1 \quad \sigma_2$ PRINCIPLE MOMENTS

EIGENVALS OF I_o

$$\alpha = \frac{1}{2}\tan^{-1}\left(\frac{2 I_{xy}}{I_{xx} - I_{yy}}\right)$$

EXAMPLE FEATURE SET



$\sigma_1 = \sigma_2$

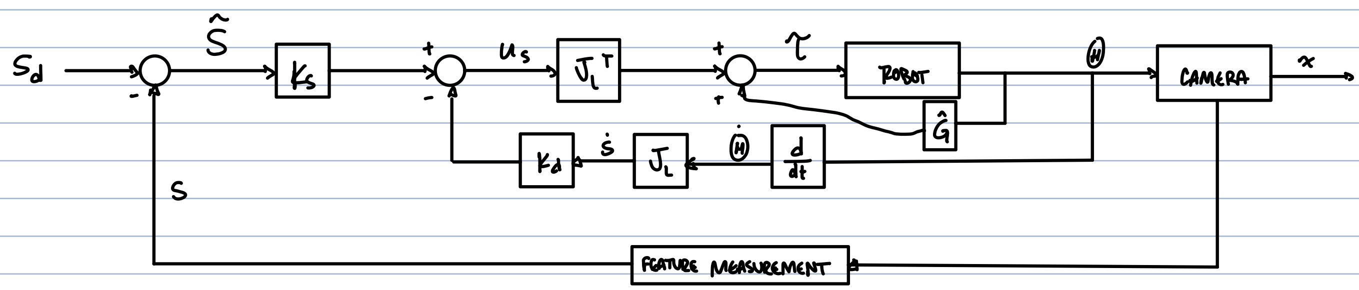
FEATURE SET

$$S = \begin{bmatrix} x_c \\ y_c \\ \frac{1}{2}(\sigma_1 + \sigma_2) \\ \frac{1}{2}(\sigma_1 - \sigma_2) \end{bmatrix}$$

AVERAGE SIZE OF OBJECT IN IMAGE

DISTORTION OF IMAGE

IMAGE-BASED VISUAL SERVOING



WE HAVE NO CONTROL OVER THIS

INTERACTION MATRIX

$$\dot{s} = J_s\, {}^{c}V_{c,o} = \cancel{J_s\, {}^{c}V_o} + L_s\, {}^{c}V_c$$

V_o = VELOCITY OF OBJECT WRT BASE FRAME

V_c = VELOCITY OF CAMERA WRT BASE FRAME

${}^{c}V_{c,o}$ = VELOCITY OF OBJECT RELATIVE TO CAMERA (IN CAMERA FRAME)

$L_s = J_s \Gamma({}^{c}x_{c,o})$

ACCOUNTS FOR FACT THAT
CAMERA ROTATION CAUSES A
FEATURE TRANSLATION

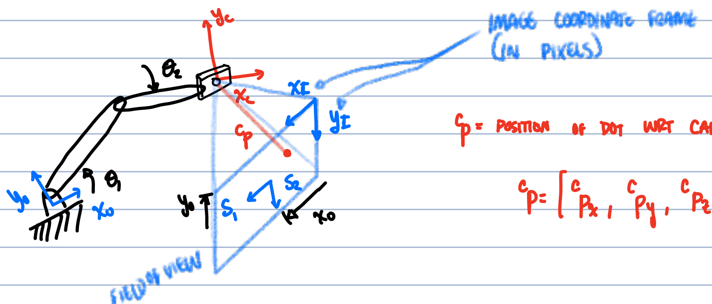
L_s MUST BE DERIVED ON A CASE-BY-CASE BASIS
· DEPENDS ON CHOICE IN FEATURES

0 FRAME = BASE FRAME
C FRAME = CAMERA FRAME

$$\dot{s} = L_s\, {}^{c}V_c = L_s\, {}^{o}R_c\, {}^{o}V_c = \underbrace{L_s\, {}^{c}R_o\, J(\Theta)}_{J_L}\, \dot{\Theta}$$

$$\therefore\ J_L^T = J^T(\Theta)\, {}^{o}R_c\, L_s^T$$

EXAMPLE: 2-DOF ROBOT TRACKING A DOT



${}^{c}p$ = POSITION OF DOT WRT CAMERA

$${}^{c}p = [{}^{c}p_x,\ {}^{c}p_y,\ {}^{c}p_z]$$

x_o y_o ARE COORDINATE FRAME IN PIXELS

COORDINATES IN MATLAB

OFFSETS

$$\begin{bmatrix} s_1 \\ s_2 \end{bmatrix} = \begin{bmatrix} x_I - x_o \\ y_I - y_o \end{bmatrix} = \begin{bmatrix} -\alpha\, {}^{c}p_x \\ -\alpha\, {}^{c}p_y \end{bmatrix}$$

(PIXELS) (METERS)

α = SCALING FACTOR (PIXELS/m)
EXPERIMENTALLY CALIBRATED

CAN SHOW

$$\begin{bmatrix} \dot{s}_1 \\ \dot{s}_2 \end{bmatrix} = \underbrace{\begin{bmatrix} \alpha & 0 & s_1 \\ 0 & \alpha & s_2 \end{bmatrix}}_{\substack{L_s \\ [2\times 3]}} \begin{bmatrix} x_c \\ y_c \\ \omega_z \end{bmatrix}$$

$\phi_2 = \theta_1 + \theta_2$

$${}^{o}R_c = \begin{bmatrix} c\phi_2 & -s\phi_2 & 0 \\ s\phi_2 & c\phi_2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$J_L = L_s\, {}^{o}R_c\, J(\Theta)$$

$$[2\times 2] = [2\times 3]\ [3\times 3]\ [3\times 2]$$

DIFFERENT JACOBIAN

· WE'RE FACTORING IN FIRST, SECOND, & 6TH ROWS OF FULL VELOCITY JACOBIAN (ω_z)